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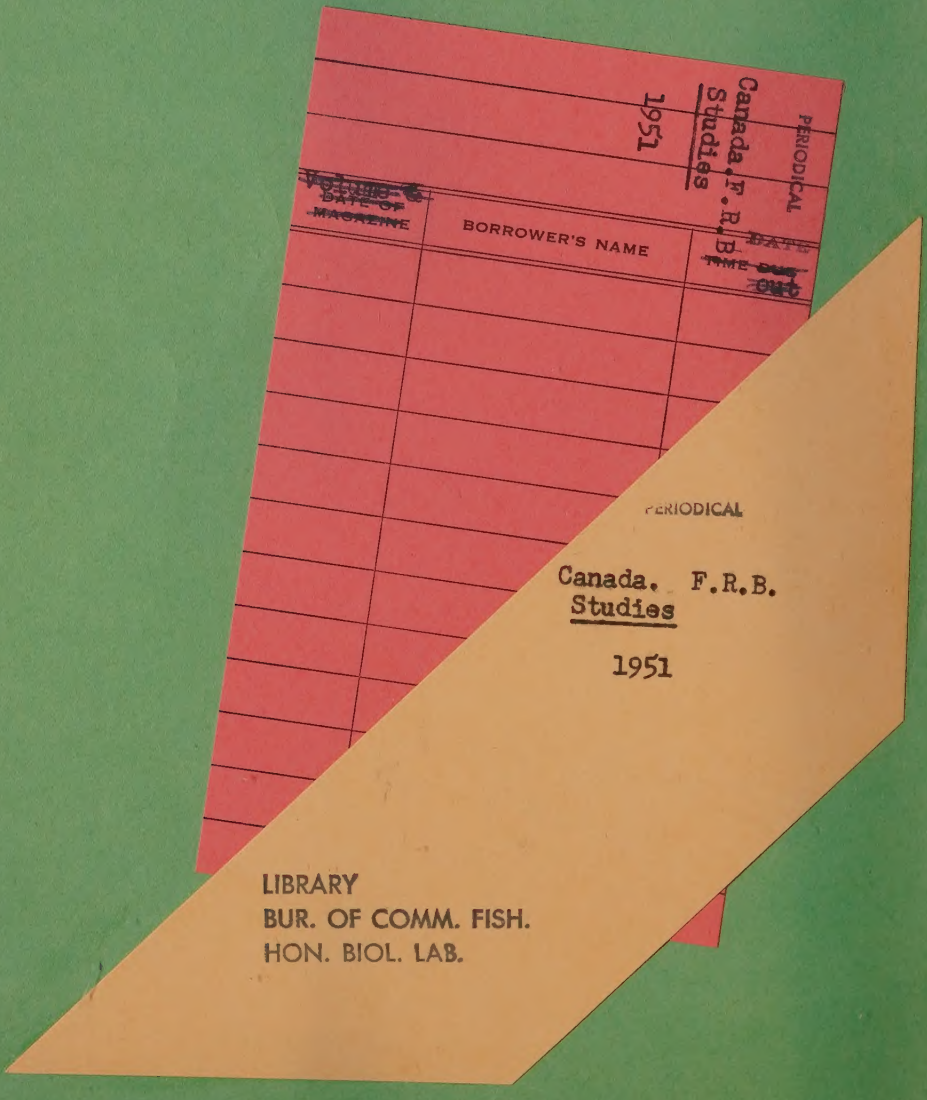
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STUDIES FROM THE STATIONS
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AN INCREASING ATLANTIC INFLUENCE IN HUDSON BAY

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Atlantic Oceanographic Group
St. Andrews, N. B.

(Received for publication 8th September, 1950)

Abstract

A comparison of oceanographic observations in Hudson Bay and Hudson Strait, made during the "Northern Cruise" of H. M. C. Ships in September 1948, with those made during the Hudson Bay Fisheries Expedition in 1930 indicates that the waters of Hudson Bay are not dynamically dead, and that the increased temperatures and salinities of the main water mass are due to an increased Atlantic influence.

INTRODUCTION

The waters of Hudson Bay and Hudson Strait are comparatively well known, and, while considerable attention has been given to this area over the past quarter century from the navigational point of view, little serious study has been given to the many and varied oceanographic problems of the area.

The first known attempt to determine oceanographic conditions in the Hudson Bay region was made by Beauchemin in 1929 (Andersen 1931), while the first detailed examination was made by one of the authors (Hachey, 1931) while officer in charge of the Hudson Bay Fisheries Expedition in 1930. The northern cruise of R. C. N. ships in 1948 provided an opportunity of making limited but detailed oceanographic observations which, when compared with those made in 1930, allow for some interesting deductions on the increasing Atlantic influence in these areas.

The general geography of Hudson Bay and Strait

Hudson Bay, connected to the Arctic by Foxe Channel, and to the Atlantic by Hudson Strait, is a shallow flooding of

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the Great Continental Shelf surrounding the North Polar Sea (Canada Year Book, 1947, p. 9). Constituting an inland sea, about 250,000 square miles in area, into which is poured the drainage water from 1,500,000 square miles of continent, Hudson Bay has the character of an enormous estuarial basin. While soundings are too few to give a complete picture of the submarine physiography, the average depth of Hudson Bay is about 70 fathoms (128 metres). The greatest charted depth of 141 fathoms (258 m.) is found in the centre of the bay and a deep water channel extends from this central depression to the greater depths of Hudson Strait.

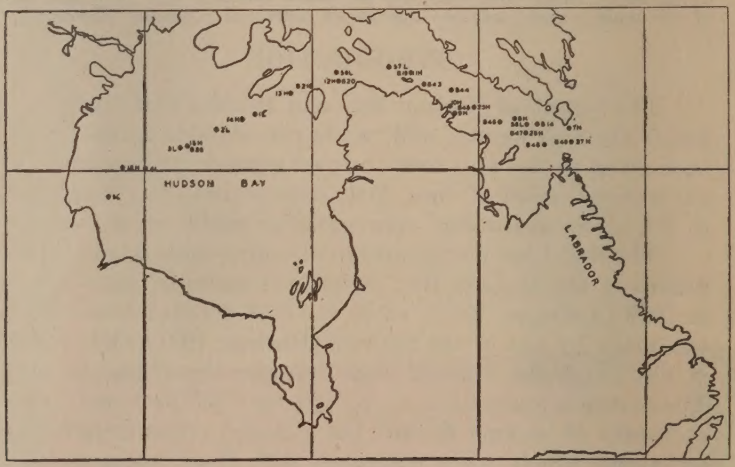

Figure 1. Hudson Bay and Strait showing the locations of "Haida" stations and positions of bathythermograph observations. September, 1948, and "Loubyrne" stations in 1930.

Hudson Strait, 430 miles in length, connects Hudson Bay with the Atlantic Ocean. The width of the strait varies from 37 miles at the entrance to 120 miles near its western extremity, and the greatest charted depth is 481 fathoms (874 m.). The high bold and broken coasts, the extremely irregular sea-floor, and the swift tidal currents combine to present what must be a mixing area of considerable extent, and must have an important role in determining the oceanographical features of the area.

The "Haida" observations 1948.

On the northern cruise of R. C. N. ships in 1948, the opportunity was provided of occupying a limited number of hydrographic stations from H. M. C. S. "Haida." Eight stations were occupied in Hudson Strait, five in early September

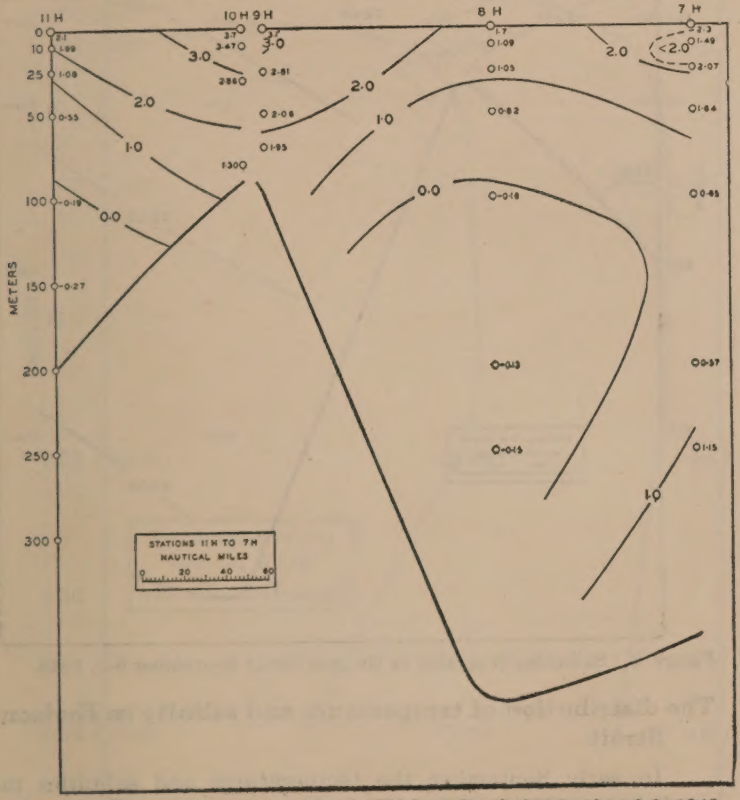

Figure 2. Temperatures in section in Hudson Strait September 6-9, 1948.

and three in late September, while six stations were occupied in Hudson Bay. The locations of all stations are shown in Figure 1. In addition, the detailed vertical temperature dis-

tribution was obtained at 50 mile intervals from bathythermograms (Spilhaus, 1938).

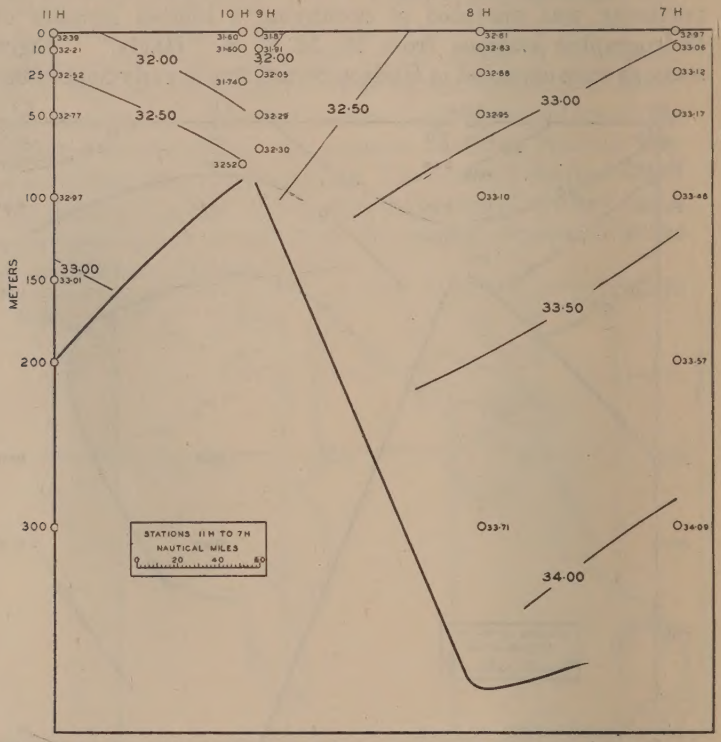

Figure 3. Salinities in section in Hudson Strait September 6-9, 1948.

The distribution of temperature and salinity in Hudson Strait

In early September the temperatures and salinities in section show Hudson Strait to be an area of intense water movements as indicated by the slope of the isotherms and isohalines in Figures 2 and 3. The main body of water in Hudson Strait, lying below the isotherm of 1.0° C., has salin-

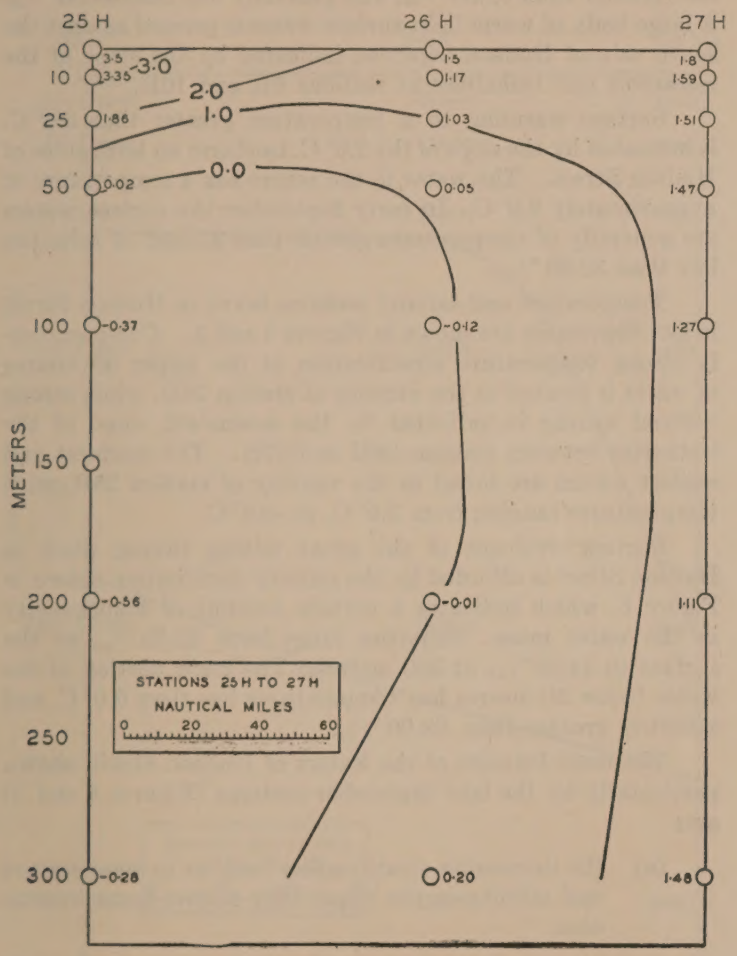

Figure 4. Temperatures in section in Hudson Strait September 20-23, 1948.

ities greater than 32.50 °/₀₀, and generally less than 34.00 °/₀₀. A large body of warm light surface water is pressed against the south side of Hudson Strait as indicated by the slope of the isotherms and isohalines at stations 9H and 10H.

Surface warming to a temperature greater than 3.0° C. is indicated by the slope of the 2.0° C. isotherm on both sides of Hudson Strait. The water in the centre has a temperature of approximately 2.0° C. In early September the surface waters are generally of temperatures greater than 3.5 and of salinities less than 32.00 °/₀₀.

Temperature and salinity sections taken in Hudson Strait in late September are shown in Figures 4 and 5. Comparatively strong temperature stratification of the upper 50 metres of water is located in the vicinity of station 25H, while strong vertical mixing is indicated by the downward slope of the isotherms between stations 26H and 27H. The warmest and coldest waters are found in the vicinity of station 25H, with temperatures ranging from 3.5° C. to -0.6° C.

Further evidence of the great mixing taking place in Hudson Strait is afforded by the salinity distribution shown in Figure 5, which indicates a certain amount of homogeneity in the water mass. Salinities range from 32.50 °/₀₀ at the surface to 34.00 °/₀₀ at 300 metres. The main portion of the water below 50 metres has temperatures less than 0.0° C. and salinities greater than 33.00 °/₀₀.

The main features of the waters of Hudson Strait, shown particularly by the late September sections (Figures 4 and 5) are:

(a) the decreasing stratification both as to temperature and salinity in the upper fifty metres from west to east;

(b) the vertical mixing as shown by the comparative uniformity of temperatures and salinities in the eastern portion of the strait; and

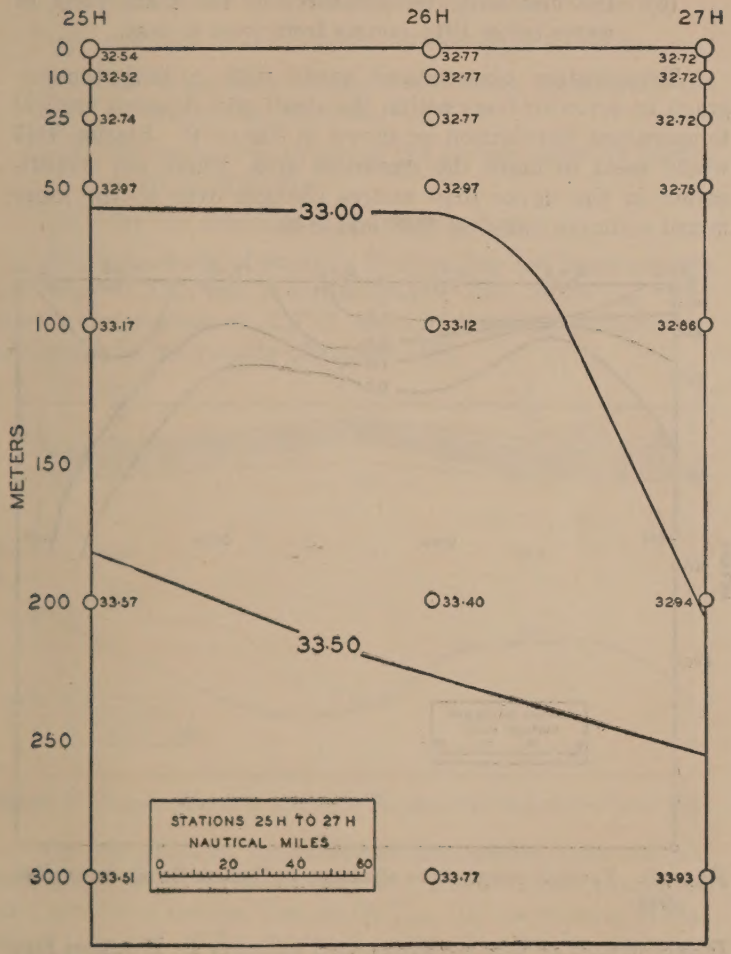

Fig 5. Salinities in section in Hudson Strait September 20-23, 1948.

(c) the increasing temperatures of the main body of water below fifty metres from west to east.

Temperature observations made with a bathythermograph at seven stations within the strait give detailed vertical temperature distribution as shown in Figure 6. Station B47 would seem to mark the transition area, where the stratification in the upper fifty metres changes over to the more mixed columns found at B48 and B49.

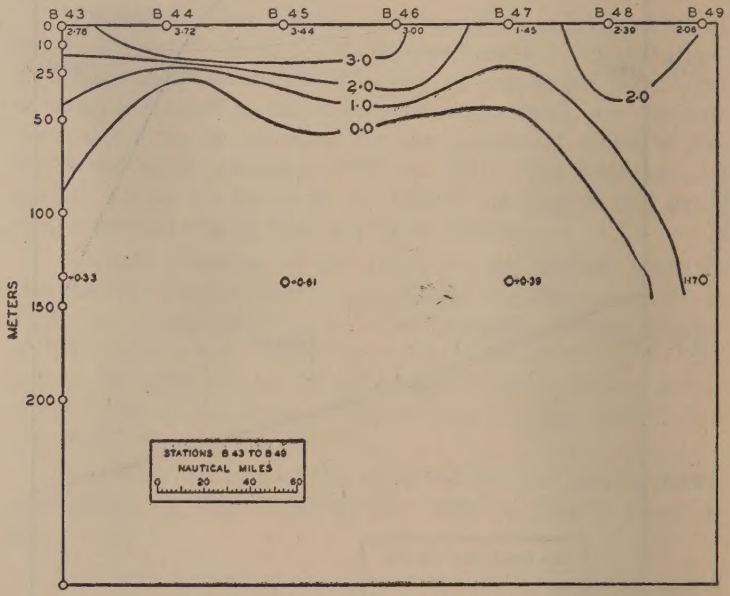

Figure 6. Vertical temperature structure in Hudson Strait September, 1948.

Distribution of temperature and salinity in Hudson Bay

Temperatures and salinities in September 1948 are plotted in a section running southwest from Hudson Strait to Churchill in Figures 7 and 8.

The main features of the waters in Hudson Bay are:

(a) the marked stratification of the upper 50 metres;

(b) the main body of cold water below 50 metres with temperatures less than -1.0° C.,

(c) the isothermal nature of the surface layers to depths of 10 to 25 metres;

(d) the low salinities in the surface layers.

The main body of water in Hudson Bay has temperatures less than -1.0° C. and salinities greater than 32.50 °/₀₀. The lowest temperature of -1.6° C. and a high salinity of 33.50 °/₀₀ are found in the vicinity of station 15H.

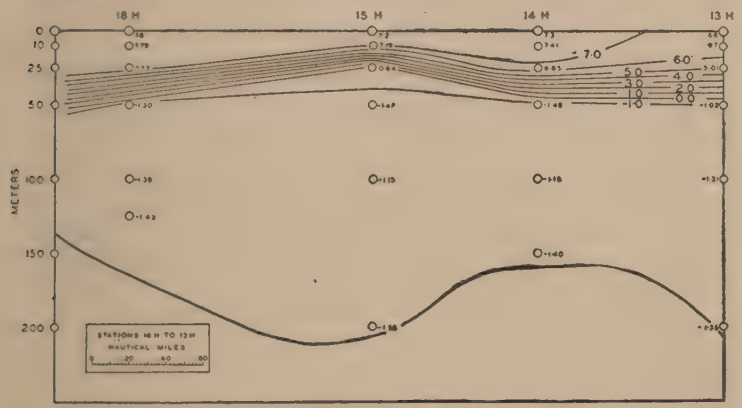

Figure 7. Temperatures in section in Hudson Bay September 9-16, 1948

On the surface, temperatures are greater than 6.8° C., with a high of 7.8° C. at station 18H. All salinities down to the 25 metre level are less than 31.00 °/₀₀. In the vicinity of stations 14H and 15H a body of water of salinities less than 29.30 °/₀₀ is found.

Typical bathythermograph traces, running in succession from Hudson Bay to the mouth of Hudson Strait, are shown in Figure 9. The waters of Hudson Bay, as indicated by these

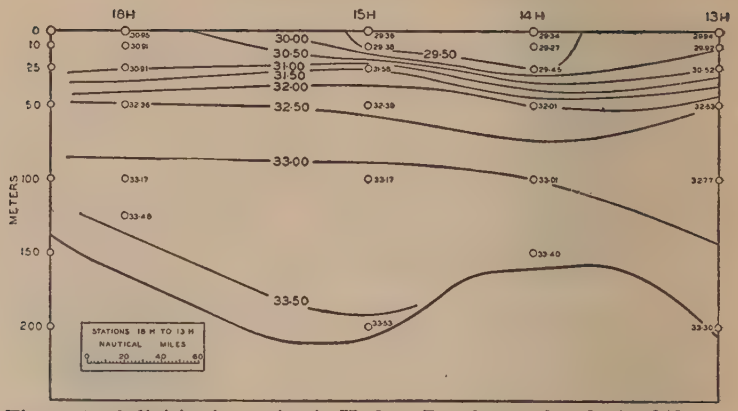

Figure 8. Salinities in section in Hudson Bay September 9-16, 1948.

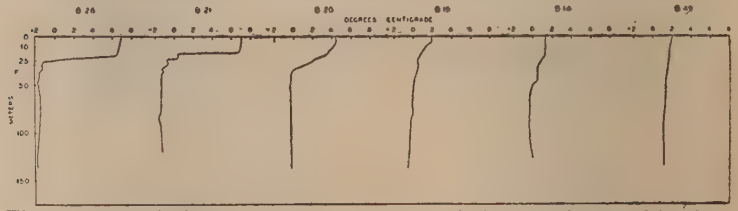

Figure 9. Typical bathythermograph traces in Hudson Bay and Hudson Strait running in succession from Hudson Bay to the mouth of Hudson Strait.

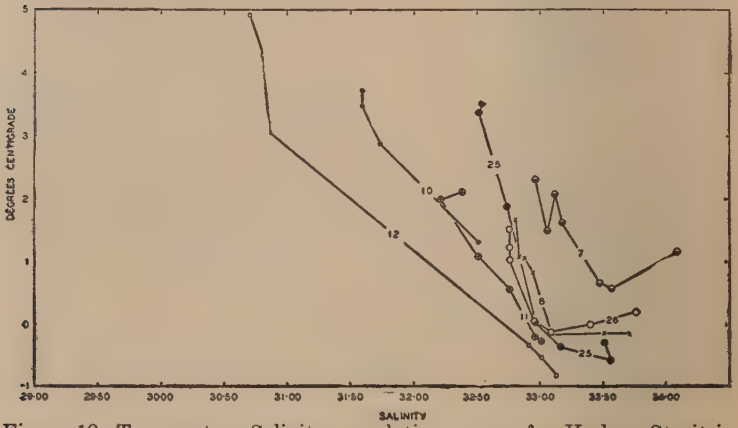

Figure 10. Temperature-Salinity correlation curves for Hudson Strait in September, 1948.

traces, are shown to have a very marked transition between the surface waters, which are warm and nearly isothermal, and the cold isothermal main body of water in the bay. On approaching Hudson Strait the depth of the isothermal surface layer is seen to decrease and the main body of water seems perceptibly warmer. On passing through Hudson Strait the increased temperature of the deep waters and the lowered temperature of the surface waters are indicative of vertical mixing, until, at the mouth of Hudson Strait, all of the water to a depth of 150 metres has a uniform temperature of approximately 2.0° C. Thus a decrease of 5.0° C. in temperature at the surface and an increase of 2.8° C. at the 100 metre level are to be observed in the west to east passage through Hudson Strait.

Temperature-salinity diagrams

On the basis of the observations made from "Haida" in September, 1948, the temperature and salinity relationships in Hudson Strait are shown in Figure 10. The diagram gives pre-eminence only to two characteristic water masses as follows:

(a) A-water exhibiting temperatures greater than 3.5° C. and salinities between 30.50 and 32.00 °/₀₀;

(b) B-water exhibiting temperatures between -0.8 and 0.1° C., and salinities between 32.90 and 33.80 °/₀₀.

The character of A-water, found at the surface, is greatly influenced by land drainage which causes a large variation in salinities. B-water, found below the fifty metre level, has the characteristics of Baffin Land Current water (Smith, Soule and Mosby, 1937) and is probably of the same characteristics as Foxe Basin water. There are indications of the influence of water of the West Greenland Current as indicated by salinities greater than 33.50 °/₀₀ (Smith, Soule and Mosby, 1937). All other water is a mixture of A-water and B-water.

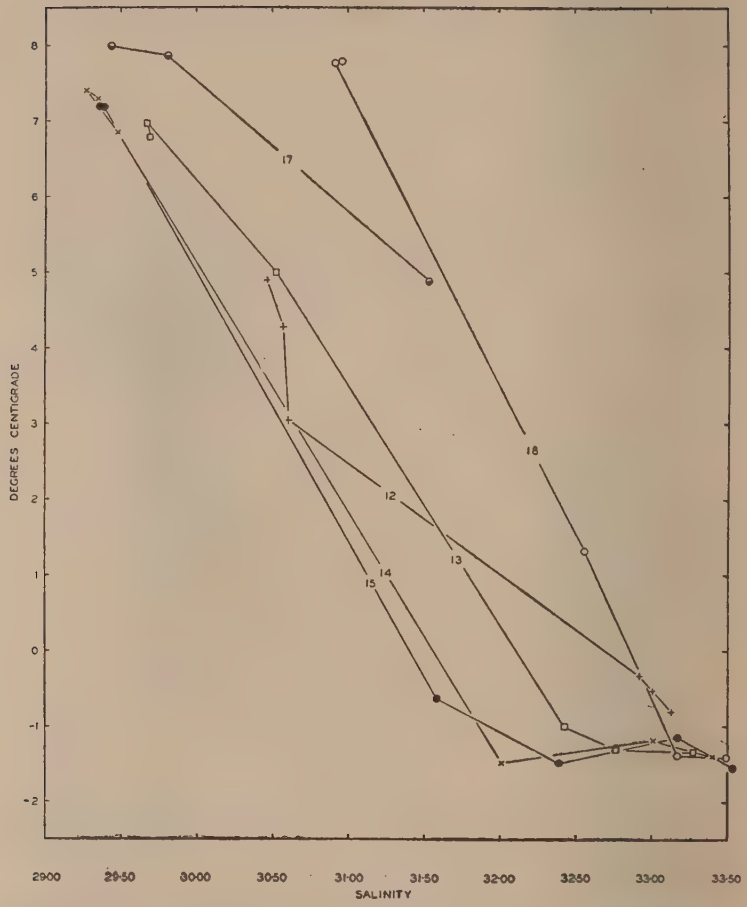

Figure 11. Temperature-Salinity correlation curves for Hudson Bay in September, 1948.

The T-S diagram shows that the inner stations in Hudson Strait (stations 11H and 12H) tend to be colder at greater depths than the outer stations 8H, 25H, and 26H. The latter stations contain waters of the Baffin Land Current, slightly modified, at greater depths, by the West Greenland Current, while the former stations contain waters from Foxe Basin.

The temperature and salinity relationships in Hudson Bay in 1948 are shown in Figure 11. Two characteristic water masses are indicated as follows:

(a) C-water exhibiting temperatures greater than 4.0° C. and salinities less than 31.50 °/₀₀;

(b) D-water exhibiting temperatures between -0.5 and -1.5° C. and salinities between 32.00 and 33.50 °/₀₀.

C-water is of the surface layer which is largely influenced by land drainage and surface warming. D-water found below the fifty metre level is, probably in greater part, surface water that has cooled during the winter when the surface waters have salanities greater than 32.00 °/₀₀ and has sunk to its own density level. In lesser part, D-water contains the higher salinities derived from water movements from Foxe Channel or Hudson Strait.

A comparison of the waters of Hudson Bay in 1930 and 1948

The temperature and salinity relationships in Hudson Bay in 1930 (Hachey, 1931) are shown in figure 12, and, in comparison with 1948 (figure 11), the characteristic D-water may be described as follows:

(a) 1930, exhibiting temperatures between -0.5 and 1.8° C. and salinities between 31.00 and 33.20 °/₀₀;

(b) 1948, exhibiting temperatures between -0.5 and -1.5° C. and salinities between 32.00 and 33.50 °/₀₀.

In addition it will be noted that salinities greater than

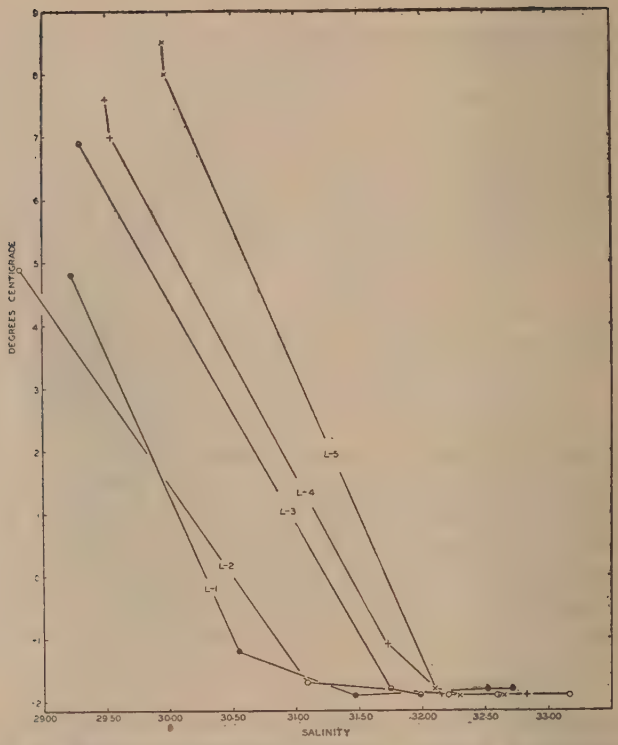

Figure 12. Temperature-Salinity correlation curves in Hudson Ba yfor August, 1930.

32.80 °/₀₀ were found only at one station in 1930, and were found at all stations in 1948. The deeper waters were generally of lower temperatures in 1930 than in 1948.

Discussion

Observations made in 1930 showed that below fifty metres the water temperatures were at least -1.8 °C. with corresponding salinities from 31.50 to 33.17 °/₀₀ (Hachey, 1931). It was concluded that the waters below fifty metres were for

all purposes dynamically dead, thus resulting in a cold, saline body of water which probably undergoes very little change from season to season. The observations in 1948 would indicate that the waters of Hudson Bay are not dynamically dead, but that there is a strong influence from the oceans through Foxe Channel and Hudson Strait. This is clearly indicated by the higher temperatures and salinities in 1948 as compared to 1930. In particular, the higher salinities are of greater significance, not only in indicating that replacement of the deeper waters does take place, but also in reflecting an increased Atlantic influence in the Sub-Artic waters.

Increasing Atlantic influence in the Greenland area as indicated by increasing salinities, the retreat of the sea ice, the weakening of Arctic water, important changes in marine fauna, including commercial fishes, and the marked reduction in the transportation of floe ice from east to west Greenland waters, has been discussed by various writers (Dunbar, 1946). This increasing Atlantic influence would seem, on the basis of the comparatively higher salinities in the deeper waters in 1948, to be reflected in the Hudson Bay area. Hudson Bay would seem to offer an excellent area for studying phenomena associated with the pulsation of the Atlantic influence in the Sub-Artic. The opportunity to study the vagaries of Arctic influence through observations of the water movements of ice and water from Foxe Basin and Channel is equally important.

Summary

I The temperature and salinity distributions in a section running through Hudson Strait are described for September, 1948, as having the main body of water of temperatures between 1.0 and -0.6° C. with salinities greater than 32.50 °/₀₀ and generally less than 34.00 °/₀₀, while on the surface, temperatures greater than 3.5° C. and salinities less than 32.00 °/₀₀ are found.

II The main features of the waters of Hudson Strait so shown by the sections are:

(a) the decreasing stratification both as to temperature and salinity in the upper 50 metres from west to east;

(b) the vertical mixing, as shown by the comparative uniformity of temperatures and salinities in the eastern portion of the strait, and

(c) the increasing temperatures of the main body of water below fifty metres from west to east.

III The temperature and salinity distributions in section are described for Hudson Bay in September 1948 as having:

(a) a marked stratification in the upper 50 metres,

(b) the main body of cold water below 50 metres with temperatures less than -1.0° C. and salinities from 32.50 to 33.50 °/₀₀, and

(c) a nearly isothermal surface layer to depths of 10 to 25 metres with temperatures as high as 7.8° C. and salinities as low as 29.30 °/₀₀.

IV Typical bathythermograph traces taken in Hudson Strait show a decrease of 5.0° C. in temperature on the surface, and an increase of 2.8° C. at the 100 metre level in the west to east passage through Hudson Strait.

V. Temperature and salinity diagrams for Hudson Bay and Hudson Strait are discussed for September 1948 and show the waters to be derived from two different water masses in each case.

VI. The waters from Baffin Land Current and from Foxe Basin are shown to exhibit similar temperature and salinity characteristics.

VII. The observations in 1948 indicate that replacement of the deep waters of Hudson Bay takes place on a large scale, the higher salinities observed, as compared to 1930, reflecting an increased Atlantic influence.

Acknowledgements

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THE VERTICAL TEMPERATURE STRUCTURE OF THE LABRADOR CURRENT

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(Received for publication 8th September, 1950.)

Abstract

The observations discussed were collected during the "Northern Cruise" of H. M. C. ships in September, 1948 while in the Labrador Current. The vertical temperature structure of the waters of the Labrador Current in the main water mass is shown to be quite stable and fairly uniform in temperature characteristics, undergoing only normal seasonal changes in the surface layers within the month of September.

INTRODUCTION

Written accounts of explorations of the Labrador Sea date back to 1266, recording details of a Norse expedition which reached the region of Smith Sound. The first recorded crossing of the Labrador Sea was by Frobisher in 1576, and, in the latter half of the nineteenth, and the early part of the twentieth centuries, considerable detailed oceanographic observations were made in this area.

It was not until the "Chance" expedition of 1926 that an attempt was made to study the detailed physical and chemical structure of the Labrador Current (Iselin, 1927). In the period 1928-35, the "Marion" and "General Greene" expeditions, sponsored by the U. S. Coast Guard, made intensive and detailed study of the waters of the Labrador current (Smith, Soule and Mosby, 1937).

In 1948 a northern cruise of H.M.C. ships provided the opportunity of making certain limited observations in the Labrador Current while on board H.M.C.S. "Haida" under Lieut-Commander Pickard. While in the Labrador Current, ten hydrographic stations were occupied by the "Haida", seven while proceeding northward and three on the return journey. At each hydrographic station water samples and

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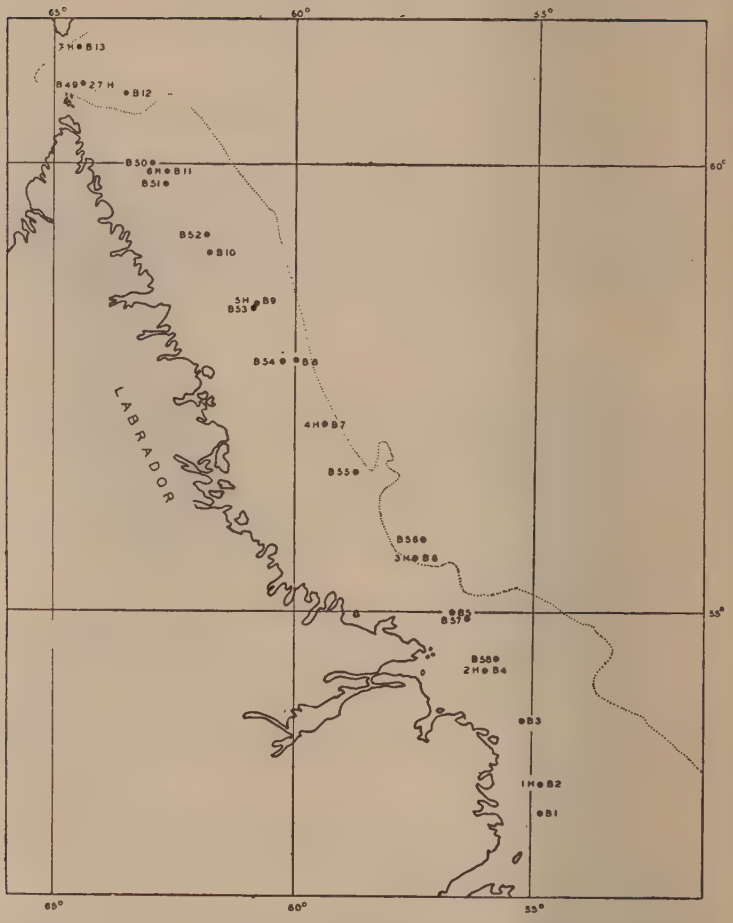


Figure 1. Labrador coastal waters showing the positions of "Haida" observations in September, 1948.

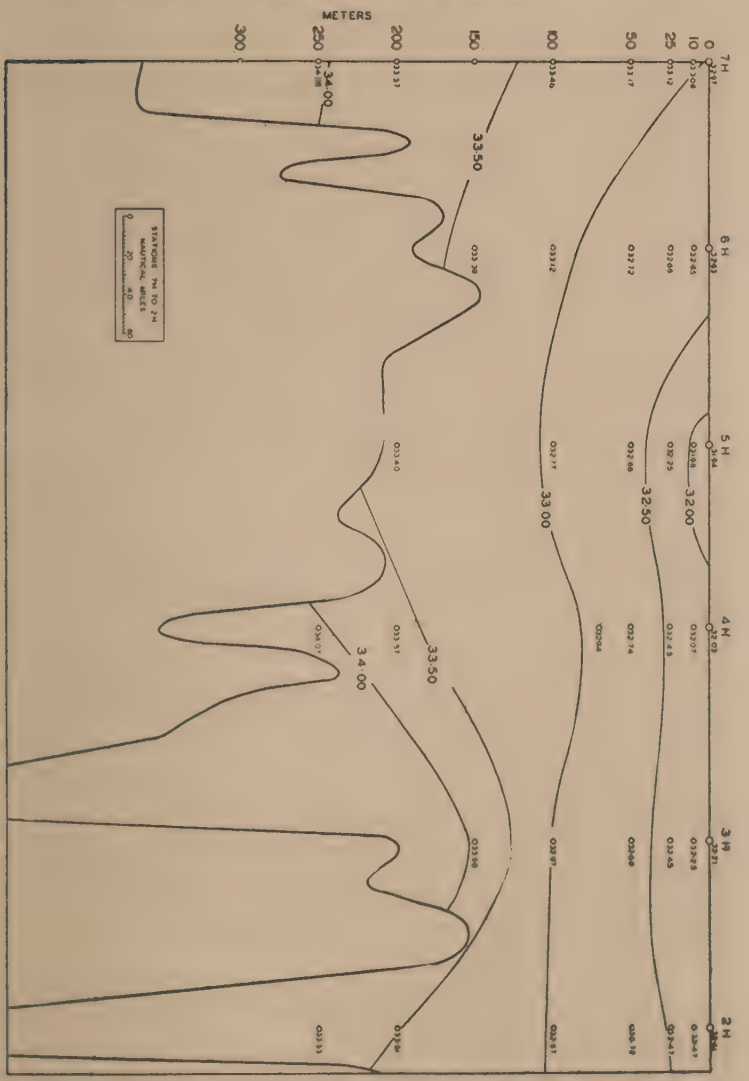
temperatures were obtained at depths of 0, 10, 25. 50, 100, 150. 200 and 250 metres. Throughout the cruise, bathythermographic observations were taken at intervals of approximately 50 miles, to depths of 150 metres. A map of the Labrador coast given in Figure 1 shows the hydrographic stations and the positions of bathythermograph observations during September. 1948.

The Labrador Current

The Labrador Current has been described (Iselin, 1927) as a cold water stream which flows southward over the continental shelf inside of the comparatively motionless homogeneous mass of North Atlantic water. As compared with the main body of water in the Labrador Sea, the current is characterized by its low salinity and temperature. As a result of the investigations of the "Marion" and "General Greene" expeditions (Smith, Soule and Mosby, 1937), the Labrador Current is found to have its origin in the vicinity of Cumberland Sound where the West Greenland and Baffin Land Currents join.

The Labrador Current may be divided into two streams, an inshore and an offshore one. The inshore stream contains the greater volume of the cold water and is confined to the continental shelf. This stream enters Hudson Strait on the Baffin Land side, and flows as far as Big Island before it recurves southward to mix with the waters flowing out of Hudson Bay, and flows out past Cape Chidley (Smith, Soule, and Mosby, 1937). The offshore stream which contains waters that are characteristic of the warmer West Greenland Current, tends shorewards near the mouth of Hudson Strait, but does not enter, and continues to flow southward over the continental slope (Smith, Soule and Mosby, 1937). Continuing down the coast, the Labrador Current follows an easy sinuous course which exhibits two major bends, the one between Cape Harrigan and Cape Harrison, Labrador, and the other between

Figure 2. Labrador Current July 22 - September 17, 1928. The velocities shown in miles per day indicate the axis of maximum flow.


METERS
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50
100
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200
250
300
7 H
6 H
5 H
4 N
3 N
2 N
32.87
32.93
32.94
32.91
32.91
32.91

Cape Bauld and Funk Island, Newfoundland (Smith, Soule and Mosby, 1937).

The characteristic low temperatures of the Labrador Current persist as the water flows southward, the great stability of the water layers preventing the penetration of solar heat by convection. On reaching the vicinity of Belle Isle Strait, water from the inshore stream is carried, at times, through Belle Isle Strait, water moving outward along the southern side of Belle Isle Strait entering into the southward flow of the Labrador Current. Continuing southward of Belle Isle Strait, the Labrador Current meets the northern face of the Grand Banks in the latitude of St. John's, and is split, the slope branch continuing down the edge of the Grand Banks, while an inshore branch follows the fully past Cape Race (Smith, Soule and Mosby, 1937).

A velocity diagram of the Labrador Current (Smith, Soule, and Mosby, 1937) is shown in Figure 2, and the axis of maximum flow is indicated by the velocities shown in miles per day.

In section, from southeast to northwest, the distribution of temperature and salinity in the Labrador Current in September is shown in Figures 3 and 4, the locations of the hydrographic stations occupied being indicated in Figure 1.

Near the axis of the Current, the main water mass constituting the Labrador current between depths of 25 and 250 metres has temperatures from 2.0 to -0.4° C. and salinities ranging from 32.50 to 33.50 °/₀₀. To some extent, the surface layer to depths of 25 metres is influenced by surface warming and land drainage, with temperatures greater than 4.0° C. and salinities less than 32.00 °/₀₀.

A large body of cold water of temperatures less than 0.0° C. and salinities between 33.00 to 33.50 °/₀₀ is located in the southern portion of the section. This is arctic water which, on the basis of salinity, is either continuous with an offshore water moving southward along the edge of the shelf, or the last vestiges of the southerly movement of Arctic water masses

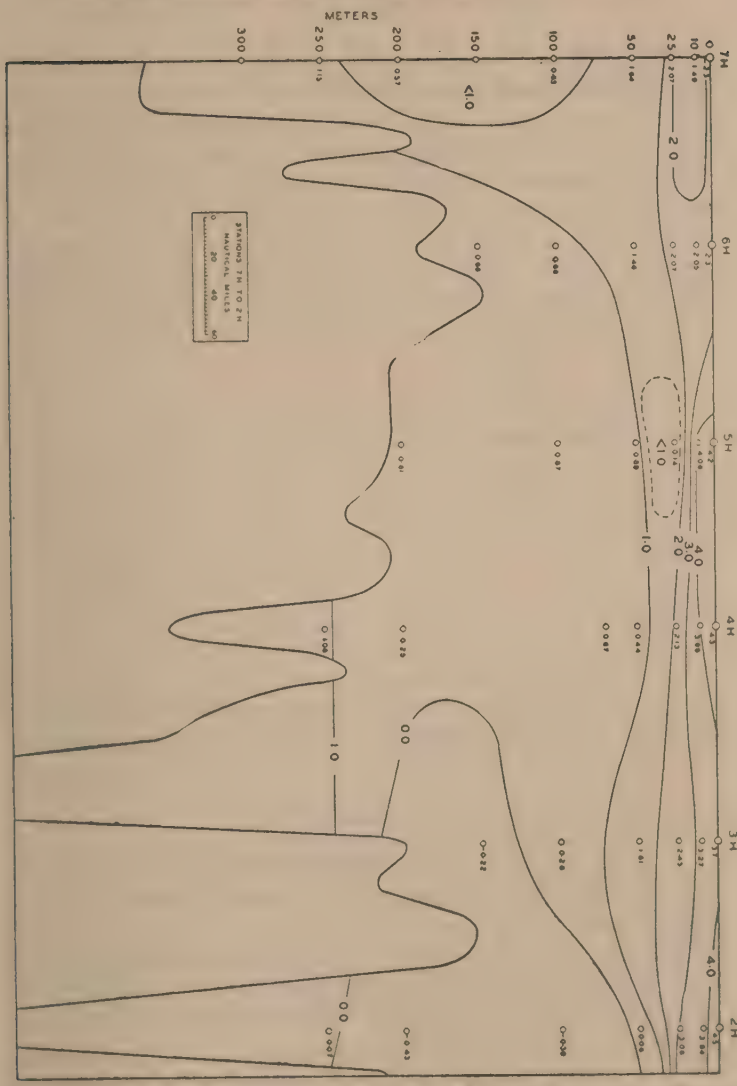

Figure 4. Salinities in section September 4-6, 1948, running northwest along the Labrador coast.

which predominate in the early months of the year (p. 122, Smith, Soule and Mosby, 1937).

In the extreme northern portion of the section (station 7H), in the vicinity of the entrance to Hudson strait, a comparative decrease in stratification, both as to temperature and salinity, is indicative of an area of mixing. Here also, at depths of 75 to 250 metres, is located a water mass of temperatures less than 1.0°C. and of a salinity of approximately 33.50 °/₀₀. On the basis of temperature and salinity characteristics this mass of water originates from the Baffin Land Current.

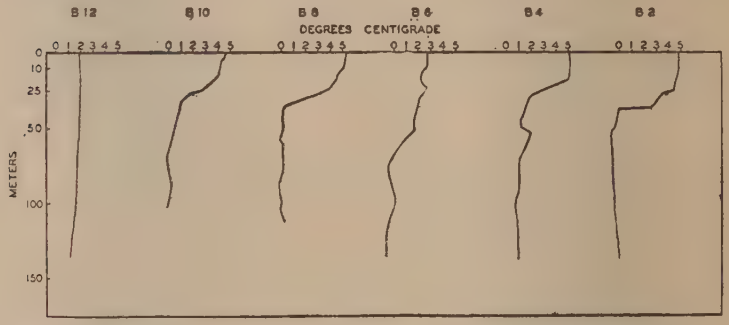

Figure 5. Temperature-Salinity correlation curves for Labrador coastal waters in September, 1948.

Temperature-salinity diagrams

On the basis of observations made in 1931 by the "Marion" and "General Greene" expedition, temperature-salinity correlation curves were obtained for all observations below a depth of 50 metres in the Labrador Current (p. 112, Smith, Soule and Mosby, 1937). These correlation curves show that the main water mass of the Labrador Current is a mixture of two characteristic waters as follows:

(1) Baffin Land water exhibiting average temperatures of -0.5 °C. and average salinities of 33.50 °/₀₀;

(2) West Greenland water exhibiting temperatures as high as 3.8° C. and salinities as high as 34.60 °/₀₀.

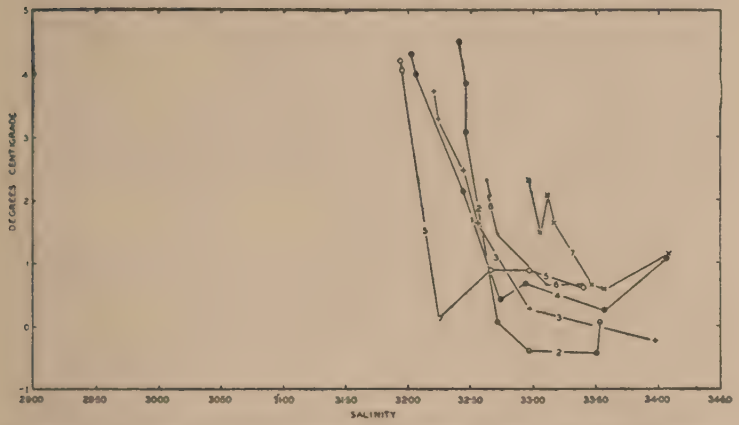

Figure 6. Typical Bathythermograph traces taken in the Labrador Current.

A temperature-salinity diagram was constructed from the 1948 data collected by the "Haida", and shown in Figure 5. As the "Haida" data were collected only along the axis of the Labrador Current, and to depths not exceeding 300 metres, the diagram gives pre-eminence only to two characteristic water masses as follows:

(1) A-water exhibiting temperatures greater than 3.0° C. and salinities between 32.00 and 32.50 °/₀₀;

(2) B-water exhibiting temperatures between -0.5° C. and 1.0° C. and salinities between 32.70 and 34.00 °/₀₀.

The A-water is therefore representative of the coastal contributions to the Labrador Current, and confined, in the main, to the upper fifty metres within the coastal belt. The B-water is obviously water of the Baffin Land Current, while no sampling of the waters of the West Greenland Current is in evidence.

The bathythermograph (Spilhaus, 1938), giving a con-

tinuous record of water temperatures from surface to depth, provides an excellent means of examining in detail the vertical temperature structure of a water mass. While in the Labrador Current, bathythermographic observations were taken from the "Haida" at intervals of fifty miles from Belle Isle Strait northward and again on the return journey. Twenty-two observations were made, twelve in early September and ten in late September. Positions of the points of observations are shown in Figure 1. Typical records are shown for early September in Figure 6.

The development of temperature stratification, as indicated between station 12B, off Hudson Strait, and station B2, north of Belle Isle is the main feature of the observations. The changing temperature characteristic of the main water mass, below 50 metres, from 0.0°C. or less at stations B2, B6, and B8 to 1.0°C. or greater at stations B4 and B12 might indicate that the sampling was not altogether along the axis of the Current. There are also traces of intrusions of small tongues of water seemingly foreign to the main water mass. These are indicated at stations B6 at depths of 10 to 30 metres and B4, at depths of 50 to 75 metres. The variation in thickness of an approximately isothermal layer from 5 metres at station B10 to 20, 17, and 25 metres at stations B8, B4, and B2 respectively, is another feature of interest.

The bathythermographic observations taken in the Labrador Current were plotted to illustrate the vertical temperature structure in section. The data for early September based on twelve bathythermograms are plotted in Figure 7, and the data for late September, based on ten bathythermograms are plotted in Figure 8. While the general features of the temperature structure as presented in Figures 6 and 7 are similar to those in Figure 2, the bathythermograms allow for a more precise determination of the temperature fine structure within the Current.

The early September section (Figure 6) shows several important features. There is a general stratification in the up-

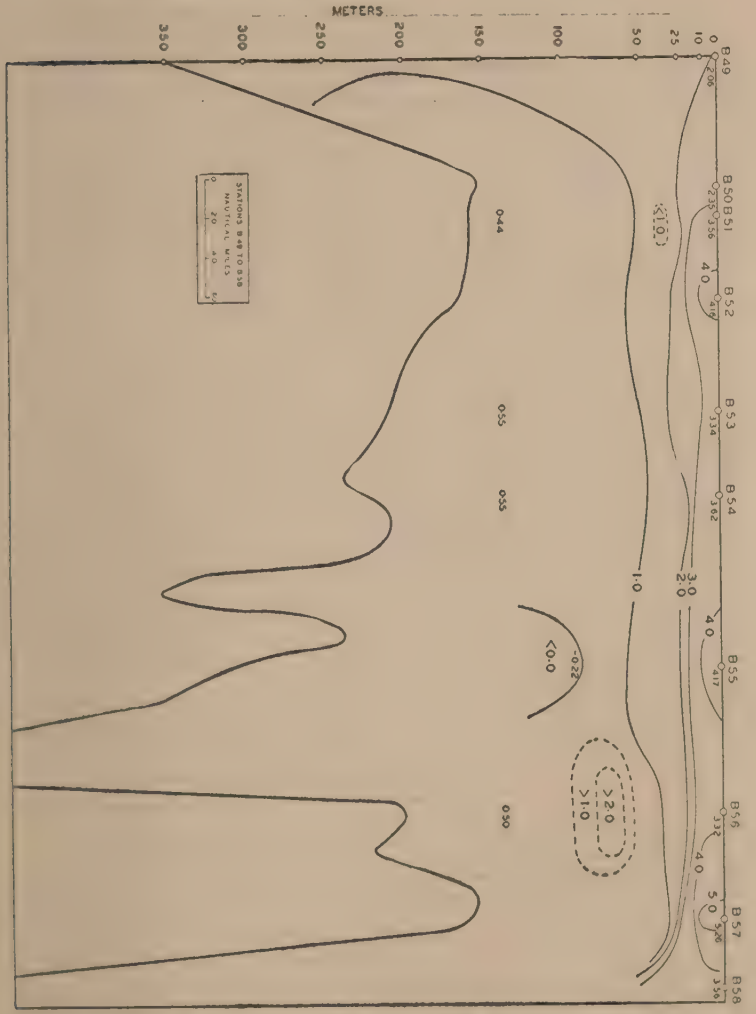

Figure 7. The Temperature structure of the Labrador current in September 4-6, 1948.

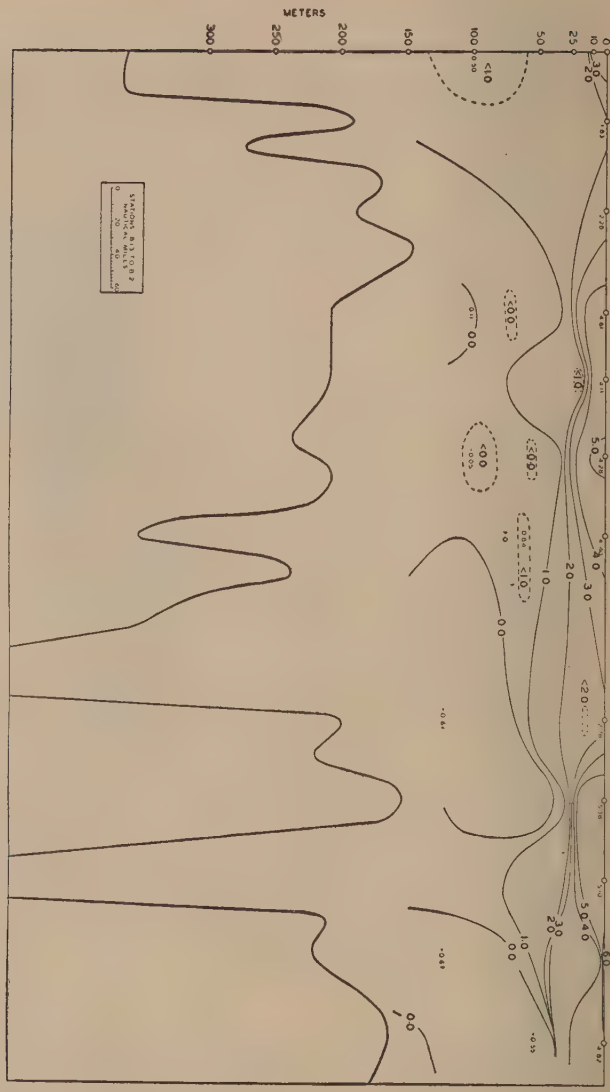

Figure 8. The temperature structure of the Labrador current in September 23-25, 1948.

per 50 metres that deepens towards the southern end of the section. This is clearly indicated by the depth of the isotherm of 2.0° C. which appears at a depth of 25 metres in the north and 45 metres in the south. The waters below the 50 metre level are, on the average, below 1.0° C. with a minimum of -0.67° C. Near Hudson Strait, the discontinuity of the isotherms at station B12 indicates that this is an area of strong mixing. Although the intensity of mixing is not as great as at station B12, the area of mixing appears to extend from south of station B11 almost to station B13, a distance of approximately 110 miles.

In various portions of the section traces of water temperatures, seemingly foreign to the main water mass, are to be found. In some cases these are probably tongues of cold water extending outward from the coast. The main water mass is of a temperature between 0.0. and 2.0° C., and the after effects of the summer season are shown in the surface layer, which at no point is thicker than 45 metres, and with the highest temperature in the vicinity of 5.0° C.

The late September section (Figure 8) exhibits the same general features as that for early September, with autumnal cooling and resultant vertical mixing shown in the surface layer by lowered temperatures and decreased stratification. One prominent tongue of comparatively warmer water has protruded into the section in the neighbourhood of station B 56.

Discussion

On the basis of the temperature-salinity characteristics of the water sampled at the "Haida" stations while proceeding in the Labrador current, in September 1948, it is obvious that the track of the "Haida" was in a water mass contributed, to a large extent, by the Baffin Land current, and that any water mass sampled was either of the Baffin Land Current, or a mixture of these waters with waters of coastal origin, and/or modification. Hence the water masses originating from the West Greenland Current or in the intermixing of water of the

West Greenland Current and Baffin Land Currents were on the ocean side of the "Haida" track. It has been estimated that the average volume of water contributed to the Labrador Current by the West Greenland Current and the Baffin Land Current is in the proportion of 3 to 2 (Smith, Soule, and Mosby, 1937).

The vertical temperature structure of the waters of the Labrador Current in the main water mass is shown to be quite stable and fairly uniform in temperature characteristics, undergoing only normal seasonal changes in the surface layer within the month of September.

The dynamics of the Labrador Current is to a large extent associated with a mixing process where waters of the West Greenland Current and Baffin Land Currents merge. While this merging probably takes place over a considerable area in Davis Strait and Baffin Bay and particularly along the continental shelf adjacent to Baffin Island, there is indicated by our observations a large area of mixing in the region of Hudson Strait, where probably waters from Hudson Bay and Foxe Channel merge with waters of the Baffin Land Current to create what might be termed Labrador coastal water. In any event, this additional mixing process gives acceleration to the southward movement of northern waters.

Summary

1. The temperature and salinity distributions in a section along the axis of the Labrador Current is described for September 1948, as having the main body of water at depths of 25 to 250 metres with temperatures between 2.0 and -0.4°C., and salinities ranging from 32.50 to 33.50 °/₀₀, while on the surface temperatures greater than 4.0°C. and salinities less than 32.00 °/₀₀ are found.

2. The vertical temperature structure of the water mass along the axis of the Labrador Current has been examined in some detail which reveals:

(a) The development of temperature stratification with variations in the thickness of an approximately isothermal layer from 5 metres at station B10 to 20, 17 and 25 metres at stations 8B, B4 and B2.

(b) Near Hudson Strait the discontinuity of the isotherms indicates an area of strong mixing which extends 110 miles southward from station B13.

(c) Tongues of cold water from inshore are protruding into the section.

(d) The temperature of the main water mass is between 0.0 and 2.0°C.

(e) Autumnal cooling with resultant vertical mixing is in evidence during September.

3. The vertical temperature structure of the water of the Labrador Current in the main water mass is shown to be quite stable and fairly uniform in temperature characteristics, undergoing only normal seasonal changes in the surface layer within the month of September.

Acknowledgements

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THE SPECKLED TROUT FISHERY OF PRINCE EDWARD ISLAND*

by

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The speckled trout fishery of Prince Edward Island, if not unique, at least presents features which are not commonly encountered by fish culturists whose interests are with this species. An abundance of young trout in most streams, for instance, reduces stocking to a minor need in localized situations. Again, a large number of trout run from the streams into salt water, and this propensity raises special problems. Both fresh and salt water environments are involved.

Prince Edward Island, the smallest province of Canada, has an area of 2,184 square miles, and is situated in the southern part of the Gulf of St. Lawrence. From its length of 120 miles and average width of 20 miles, it is evident that the stream systems are short and that in general we are dealing with small waters. The Island is a stabilized, prosperous farming community and a well-developed road system makes streams and artificial ponds readily accessible to anglers.

Character of Trout Production

The excellence of trout fishing in Prince Edward Island streams, estuaries and ponds has been appreciated by generations of anglers. Statistics upon the production of trout in these waters are available, however, only for recent years.

Since 1943 a creel census has been taken during each angling season (April 15-September 15) at an artificial 23-acre pond situated just above the head of tide on the North Montague River, which has a course of approximately 15 miles. A small pond was originally formed on this site over 60 years ago, and the present higher level has been held since 1917. Creel census data are given in Table I and show that the yield to the anglers has fluctuated during the period of eight years from a low of 2,403 trout in 1948 to a high of 3,819 in 1946. Expressed in other ways, the annual yield has varied from 22·4 to 44·0 pounds per acre, and the average rate of capture from 1·4 to 2·5 trout per rod-hour. The yearly average total length of the trout has remained within the narrow limits of 8·0 to 8·5 inches.

Table I

Yield of Speckled Trout to Anglers from Montague Pond, P.E.I.

	1943	1944	1945	1946	1947	1948	1949	1950
Number caught	3,731	3,801	3,533	3,819	3,061	2,403	3,097	3,622
Number of rod-hours	1,492	1,516	1,632	1,634	1,723	1,351	2,144	1,868
Number per rod-hour	2·5	2·5	2·2	2·3	1·8	1·8	1·4	1·9
Average total length (in.)	—	8·2	8·5	8·1	8·4	8·0	8·1	8·2
Average weight (oz.)	—	3·8	4·5	3·6	4·1	3·4	3·6	3·7
Pounds per acre	—	40·7	44·0	37·2	34·1	22·4	30·1	36·7

*Read at the Northeast Atlantic Fisheries Conference, Portland, Maine, March 22-23, 1951.

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Although a very considerable number of trout have been taken each year from the pond, the data present no consistent evidence that the anglers' catch of one year had a determinative influence upon that of a year later. Rather the continued good yields, although fluctuating, reflect the good reservoir of young trout to be found in the feeder stream, as is well illustrated by the following data. On September 11, 1944, seven seine hauls in pools of the stream, about four miles above the pond, captured 1,237 trout. Only 28 of these were over seven inches in notch length, while 633 were under $4\frac{1}{2}$ inches. Since only one haul was made in each pool it is to be appreciated that the captures did not represent the total number of trout present. In view of this information one might reasonably assume that a greater annual cropping of trout in the Montague Pond would not endanger the fishery.

Ellerslie Brook is a small spring-fed stream whose effective length for supporting trout, even those of the year, is limited to approximately four and one-half miles. In connection with an investigation to which reference will again be made, a two-way fish trap has been held at the mouth of this brook since June, 1946. The trap has been operated throughout each year, and since April, 1947, each trout that has moved for the first time, either into or out of the brook, has been tagged. Tagging records disclose that 2,886 trout moved through the traps during the period April 22, 1947, to April 21, 1948. Over the same periods in 1948-49 and 1949-50 the numbers were 2,287 and 2,647 respectively. These data do not, however, provide information upon those trout present in the brook which did not run to sea during those periods. Summer estimates of population in 1948, 1949 and 1950 placed the number of such trout, including fish of the year, at about 20,000 for each year. Creel censuses maintained on the brook and upper part of the estuary since 1947 have shown annual yields varying from 1,086 to 1,942 trout captured at average annual rates from 1·5 to 1·9 per rod-hour (Table II).

Table II

Yield of Speckled Trout to Anglers from Ellerslie Brook, P.E.I.

Year	Number caught	Average length (in.)	Number per rod-hour
1947	1,141	6·9	1·5
1948	1,086	7·0	1·5
1949	1,942	6·9	1·8
1950	1,608	7·0	1·9

From our knowledge of the fishery, we believe that the production levels for trout in Ellerslie Brook and Montague Pond are quite representative of those in streams and artificial ponds of Prince Edward Island generally. Except locally, and then temporarily, we are as yet concerned with under-cropping rather than over-cropping by anglers.

Environmental Conditions

The environmental conditions which make for such favourable habitats for speckled trout have been primarily determined (1) by the underlying geological formation and (2) by the insular position of the waters.

The underlying rock formation of almost the entire island consists of Neo-Permian sandstones with calcareous cements. These sandstones have weathered to provide deep porous soils which are everywhere in evidence except in low-lying areas where humus and peats have accumulated superficially. The porous soils are conducive to spring drainage and the streams are generally spring-fed, with the result that they present relatively cool aquatic environments in summer, that their levels are well maintained throughout the warm weather, and that spawning facilities for speckled trout are good.

Again because of the nature of the soils, Prince Edward Island is one of the better farming districts in the Maritime Provinces, and has justly earned the sobriquet "Garden of the Gulf". However, to sustain the fertility of the top soils, especially in the potato-farming districts, the practice of applying artificial fertilizers is wide-spread. Accordingly, the natural fertility of the streams and ponds is much enhanced by drainage from these cultivated lands, and results in a rich growth of aquatic plants and animals, a large proportion of the latter being trout foods. We here have an example of a beneficial rather than a deleterious effect upon a natural environment by man's interference.

Numerous bays, often with barrier sand islands between them and the more open sea, and estuaries running well inland at the mouths of streams, are topographical features of Prince Edward Island. These protected, shallow and productive areas are apparently suitable habitats for those speckled trout that run into them from the streams and remain for variable periods of time, for those trout make good growth during the sojourn in salt water and are among the larger trout angled from the Island waters. Thus not only the favourable character of the fresh waters but also that of the brackish and salt-water inlets contribute to the quality of the trout fishery.

Further contributing in no small way to the success of the young trout in the streams are the limited competition and predation by other species of fish. In many situations the fish fauna consists almost entirely of trout. In our experience the most serious competitors are the young of the Atlantic salmon. Because of their insular position no indigenous strictly freshwater fish are present in the Island waters. (The golden shiner has been introduced and become established in one of the few natural ponds.) Thus the fortunate combination of fertility, coolness of water, favourable spawning conditions and limited competition and predation by other species conditions Prince Edward Island streams for a high production of young speckled trout.

Problems of the Fishery

It is apparent from what has already been stated that on Prince Edward Island we are not primarily faced with the common problems that so frequently beset the attempts of fish culturists to maintain and improve speckled trout angling, such as a scarcity of young native trout, serious competition and predation by other fish, infertility of waters and high temperature. Rather, the initial problems involve the management of adequate stocks of young trout toward an increase in their number and availability at suitable

size for angling. Pond formation presents one method of meeting these problems in management, for, as exemplified by the results of the creel census at the Montague Pond, artificial ponds created on Prince Edward Island streams usually provide good angling. Pond formation is the most direct approach to overcoming a major deficiency, namely the lack of sizable natural fresh waters.

Notwithstanding its basic simplicity and directness as a means to overcome this deficiency, pond formation in turn poses other problems. As we have noted, trout run to salt water from the Island streams and they constitute the stock for a sport fishery in the estuaries and contribute to that in the fresh waters upon their return to the streams. Pond formation obviously curtails the movements of these trout upstream. Accordingly there is the problem of determining how the formation of a pond affects the trout population of a stream system as a whole—the stream and the estuary. Will the benefits accruing to anglers by forming a pond be offset by a reduction in the fishery for the sea-run individuals when these are restricted in upstream movements by dams? Also what will be the result of reducing the stream areas available to the sea-run trout for spawning, especially if pond formation is extensively applied? The reduction in spawning areas will be most serious if sea-run parents are necessary to provide sea-run progeny, but of much less significance if the sea-run group is recruited indiscriminately from the stock of young trout in the stream irrespective of parentage.

Attack on the Problems

Pond formation in itself, without attempt at regulation of density of stock or in any way manipulating the pond environment, provides, as we have shown, good angling. However, it can be practised without realization of the full potentialities of such pond areas as trout producers. Further steps in management need to be explored. We have investigations currently under way in artificial ponds on Island streams to determine the most suitable density of stock for optimum production of trout of angling size. The dams are constructed so that the ponds can be drained to the original stream level and the standing crop of trout accurately assessed. Results to date from three ponds suggest that an initial density of 400 yearling trout per acre does not utilize the full trout-producing capacity of the ponds, although with this density of stock total yields (final less initial weight of trout) of as much as 29 pounds per acre have been obtained in a three-month interval from late spring until early fall. Greater densities of stock are to be tested, and the full programme for the experimental ponds envisages tests upon further enrichment of the water with artificial fertilizers and the possibility of utilizing waste from local commercial sea fisheries to augment the food supply.

A programme of pond formation as a means to improve angling is complicated, as we have already intimated, by the fact that ponds restrict the movements of those trout that run to salt water and periodically return to the streams. At Ellerslie Brook the effect of pond formation upon the trout population of a system is being studied. Since 1946 a two-way fish trap has been maintained at the mouth of this small stream at all seasons of the year, and trout entering and leaving the brook are enumerated, measured and tagged. A creel census is kept of the trout that are angled. Stocks of young trout in the brook are evaluated each year. A pond will be formed when sufficient data for comparison are compiled from the unobstructed brook.

Fish traps at the mouth of Ellerslie Brook, P.E.I.

Simpson's Pond, P.E.I., an artificial experimental pond used in the studies of trout production.

In an attempt to gain an understanding of the relationships between the brook and sea-run groups, progeny from these two stocks of trout have been planted in Ellerslie Brook as fish of the year and as yearlings, after being marked differently by fin-clipping. As yet these planted trout have not entirely moved through the population of the system, and the data upon them are therefore incomplete. For the present it can be reported that the progeny from both parentages have run from the stream. Thus apparently the sea-run group can be recruited from a brook stock that has not been to salt water for many generations, but it is yet to be determined how effectively this may be realized.

In the programme at Ellerslie Brook the anglers' catch was one of the more important criteria by which the effects of pond formation upon the trout stock were to be gauged. We have noted that without pond formation the yield to the anglers has varied from 1,086 to 1,942 trout over a four-year period, and the rate of capture from 1·5 to 1·9 per rod-hour. Obviously the establishment of a reasonably constant level for comparative measurements of fish production in nature is difficult, even, as in this case, in a small stream. The lesson is clear that if worthwhile fish management procedures are to be developed they must rest upon data obtained over a sufficiently long period to delimit natural fluctuations.

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A COMPARISON OF NYLON AND COTTON GILL NETS USED IN THE LAKE WINNIPEG WINTER FISHERY[1]

by

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The introduction of nylon gill nets to the fishery on Lake Winnipeg during recent seasons has aroused considerable interest and some controversy among fishermen, and others. Various opinions regarding their efficiency have been expressed. Lawler (1950) suggests that in the gill net fishery for lake whitefish on Lake Erie, nylon netting is about three times as efficient as linen.

Some fishermen claim that the nylon gill net takes a greater number of small fish than an equivalent mesh size in a cotton gill net. Others feel there is no essential difference in size of fish taken, but that a nylon gill net will catch more fish than a comparable cotton gill net. Still others believe there is no real difference at all.

During January and February of the 1950-51 winter fishing season on Lake Winnipeg, Fisheries Research Board of Canada personnel of the Central Station had occasion to record data pertinent to this question. The data recorded were from the gill nets lifted by commercial fishermen fishing at various points on the ice throughout a distance of about 120 miles. For convenience, this distance was divided into three adjoining areas of approximately equal size. The fishermen from whose nets the data were taken were selected at random.

Record Weight of Each Fish

Each gill net was lifted singly during the winter fishery. As it was being lifted a record of the weight of each individual fish was taken. The fisherman was asked to report as accurately as possible the length of the gill net as well as the mesh size and net depth. The material from which the netting was made was also recorded.

Only those data from nylon and cotton gill nets reported as three-inch mesh were used in this paper. The bulk of the data was collected from gill nets which were fished under similar conditions. In only a few cases was it possible to record data from adjoining cotton and nylon gill nets.

An examination of Table I shows that in each of the areas the average weight of individual fish is generally greater in the nylon nets. This difference is evident probably because cotton nets tend to shrink with usage.

As shown in Table 1, Area 1, cotton nets caught considerably more fish per 100 yards than the nylon nets. The figure for availability (i.e. catch per unit effort) for the cotton nets is probably misleading as it was computed on only 70 yards of gill net for the whole of the area, as compared with 930 yards of nylon gill net. In Area 2 the

[1] *Received for publication May 1951.*

Table I

The average round weight of species and the average availability of representative samples of fish from nylon and cotton gill nets of three-inch mesh used in the Lake Winnipeg winter commercial fishery during January and February, 1951. The number of individuals is shown in parentheses.

		Area 1		Area 2		Area 3		All areas	
		cotton	nylon	cotton	nylon	cotton	nylon	cotton	nylon
Average weights of species (lbs.)	Sauger	0·64 (33)	0·68 (295)	0·56 (652)	0·60 (127)	0·56 (652)	0·59 (197)	0·56	0·63
	Pikeperch	1·05 (10)	0·96 (183)	0·79 (211)	0·80 (179)	0·68 (547)	0·77 (269)	0·72	0·83
	Burbot	1·17 (41)	1·47 (173)	1·72 (54)	1·32 (27)	1·05 (11)	1·35 (10)	1·16	1·44
Average catch per 100 yards of gill net (lbs.)	Sauger	30·0	21·5	11·0	14·5	5·5	11·5	7·5	15·5
	Pikeperch	15·0	19·0	5·0	27·5	5·5	19·5	5·5	21·0
	Burbot	68·5	27·5	2·0	7·0	0·18	1·0	1·0	12·0
	Other species	18·5	11·0	5·0	12·5	1·5	2·5	2·5	7·5
	All species	132·0	78·5	23·0	62·0	13·0	34·5	17·0	57·0

comparisons are based on 3,316 yards of cotton gill net and 516 yards of nylon. In Area 3, 6,420 yards of cotton gill net and 1,046 yards of nylon were used in determining the availability. In all areas, the availability of all species is roughly three times as great for nylon gill nets as for cotton ones. Total yardage for all areas is 9,806 for cotton, and 2,492 for nylon gill nets.

Regarding working characteristics, the fishermen reported that during very frosty weather nylon gill nets were more difficult to clear than the cotton ones. On the other hand, cotton gill nets became occluded by a heavy phytoplankton pulse much more quickly than did the nylon gill nets. This appeared to be an important factor in the relative size of the catches.

It seems clear that the three-inch mesh nylon gill net is considerably more efficient in the Lake Winnipeg winter fishery than the three-inch mesh cotton. The average size of fish taken in each is similar.

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STUDIES FROM THE STATIONS
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No. 320

ZOOLOGY.- *A second record of the polychaetous annelid* Potamethus elongatus (*Treadwell*). E. and C. BERKELEY, Pacific Biological Station, Nanaimo, British Columbia. (Communicated by F. A. Chace, Jr.)

The only specimen hitherto recorded of the polychaetous annelid *Potamethus elongatus* (Treadwell) is in the collection of the U. S. National Museum (no. 5221). It was taken by the steamer *Albatross* in the Hawaiian region in 1902 and briefly described by Treadwell (1906) under the name *Potamilla elongata*. The specimen was later re-examined by Hartman (1942) and attributed to the genus *Potamethus*. It was said to be fragmentary, but the essential details were described.

We have recently been fortunate enough to acquire three specimens of the species, sent to us by Dr. Clifford Carl, of the British Columbia Provincial Museum, Victoria, to whom they had been given by H. E. Wyeth, of the cableship *Restorer*. They were found on sections of the San Francisco to Manila cable brought up for repair. The length of cable involved lies in depths varying from 840 to 1,600 fathoms, about 1,000 miles east of Guam. The specimens are all in good condition and complete, though much contracted, particularly in the peristomial region. One was preserved completely enclosed in its tube, the others partially enclosed. The lengths are, respectively, 50 mm, 51 mm, and 45 mm, the width about 2 mm in each case. The branchial plume, the filaments of which are twisted together in all the specimens, makes up half, or a little more, of the over-all length.

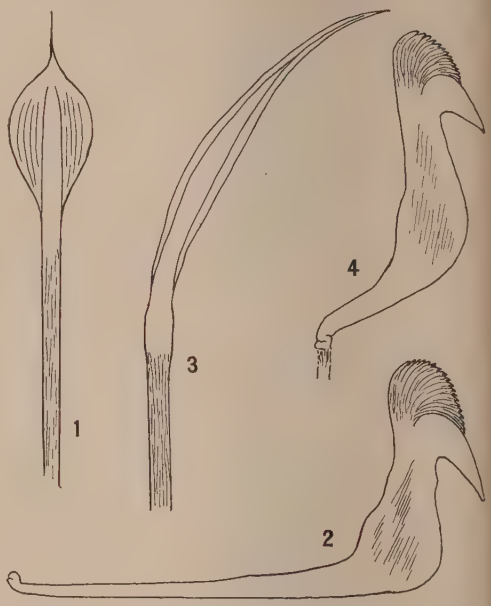
The general appearance agrees with that

of the type species of the genus, *P. spathiferus* Ehlers, the outstanding characters being the high, oblique collar, unbroken dorsally or ventrally, but rising to a high, thickened and grooved, lobe on the dorsal side, the slender body, and the very long branchial filaments (Ehlers, 1887, pl. 54). The dorsal collar lobe varies considerably in appearance in each of the three specimens and is evidently mobile. The long peristomial region, which Ehlers shows for *P. spathiferus* and Hartman says is present in *P. elongatus*, is not apparent in our specimens, but this region is much wrinkled because of contraction and would, no doubt, appear as shown by Ehlers in extension. The branchial bases are slightly, but definitely, involute on the ventral side.

As Hartman points out, *P. elongatus* is definitely differentiated from *P. spathiferus* by the form of the spatulate setae, those of the former species having long mucrons, whereas in the latter they are very little developed. The asymmetry of the blades of these setae in *P. elongatus*, which she stresses, is not invariably present in our specimens; some correspond closely with her figure 15d, others are as symmetrical as shown in our Fig. 1 and by Treadwell (fig. 74), and every intergrade is represented. The form of the thoracic uncinus in our specimens is also not completely in accord with that shown by Hartman (fig. 1c) or by Treadwell (fig. 75). As we find them the stems curve very little or not at all and taper very slightly and gradually, the crests are somewhat higher, and the angle between the beak and neck is rather smaller (fig. 2). These differences may well be within the limits of variation.

The abdominal setae are of two kinds, long capillaries with very narrow blades and others much shorter with wide, flat terminal blades set at a slight angle to the shafts (fig. 3). The abdominal uncini are as shown in Fig. 4. The tubes are quite smooth, the walls very thin and fragile and coated with very fine mud.

Four species have been ascribed to the genus *Potamethus*, all from considerable depths. Of these *P. mucronatus* (Moore), *P. spathiferus* (Ehlers), and *P. elongatus* (Treadwell) seem to be sufficiently clearly differentiated (see Hartman, 1942). There



FIGS. 1–4.—*Potamethus elongatus* (Treadwell): 1, Spatulate thoracic seta; 2, thoracic uncinus; 3, short abdominal seta; 4, abdominal uncinus.

remains *P. scotiae* Pixell. The only notable difference between this species and *P. elongatus* (Treadwell) appears to be in the form of the thoracic uncinus, particularly its very long stem and curious crest (Pixell, 1913, figs. 7a, 7b). Having regard to the variability of the setae in *P. elongatus* we have indicated, we consider it not improbable that the two species are synonymous.

One of the three specimens dealt with in this note is deposited in the U. S. National Museum (no. 22752); the others remain in the authors' collection.

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Further Observations upon the Movements of Speckled Trout in a Prince Edward Island Stream

by

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The movements of speckled trout into and out of Ellerslie Brook, Prince Edward Island, have been under observation since June, 1946, in connection with a study of the relationship between the sea-run and brook populations and of the effects on these stocks of making artificial ponds. The movements of the trout during the first 15 months of observation (Smith, Fish. Res. Bd. Can., Prog. Rep. Atl., No. 43, Note No. 107, pp. 9-13, 1948) suggested a definite pattern, but subsequent observations have shown that the movements vary from year to year.

The trout moving into and out of Ellerslie Brook are captured in a two-way fish trap which is situated near the head of tide. The trap is operated throughout the year. Daily records are obtained of the number of trout that move each way. On its first passage each trout has a numbered monel metal tag attached to the lower jaw. During the angling season from April 15 to September 15 a creel census is taken of the trout angled from the brook and from the estuary below the trap.

Ellerslie Brook, including one tributary, has a total permanent length of about four miles, but not more than one-half that length supports trout over one year in age during the summer months. The drainage area, consisting in large part of productive farming land, is about eight square miles. The brook is tributary to Smelt Creek, which in turn is an arm of Malpeque Bay.

The Movements

As illustrated in Figure 1, the migrations of the trout may be roughly divided into two categories: (1) those that have recurred each year at about the same time, and (2) those that have been more sporadic but, in some instances, involving large numbers of trout.

Of the first category are the movements up-stream in June and July, and up- and down-stream during the fall and early winter (October to December). The early-summer inward movements are quite well known to resident anglers because of their comparative regularity and their contribution to the angling in the streams at that season, and have been termed "strawberry runs". In 1948 this movement was in two pulses, while in 1949 it started earlier than usual, with the result that a good number of trout entered the brook in late May. Less appreciated by the general public are the upward movements of trout from salt water each year during the spawning period in the fall and early winter. During the same period there have occurred large outward movements from the brook. It is to be understood that the trout involved in the up- and down-stream fall runs are for the most part different individuals and not the same fish going through the traps several times during a short period of time.

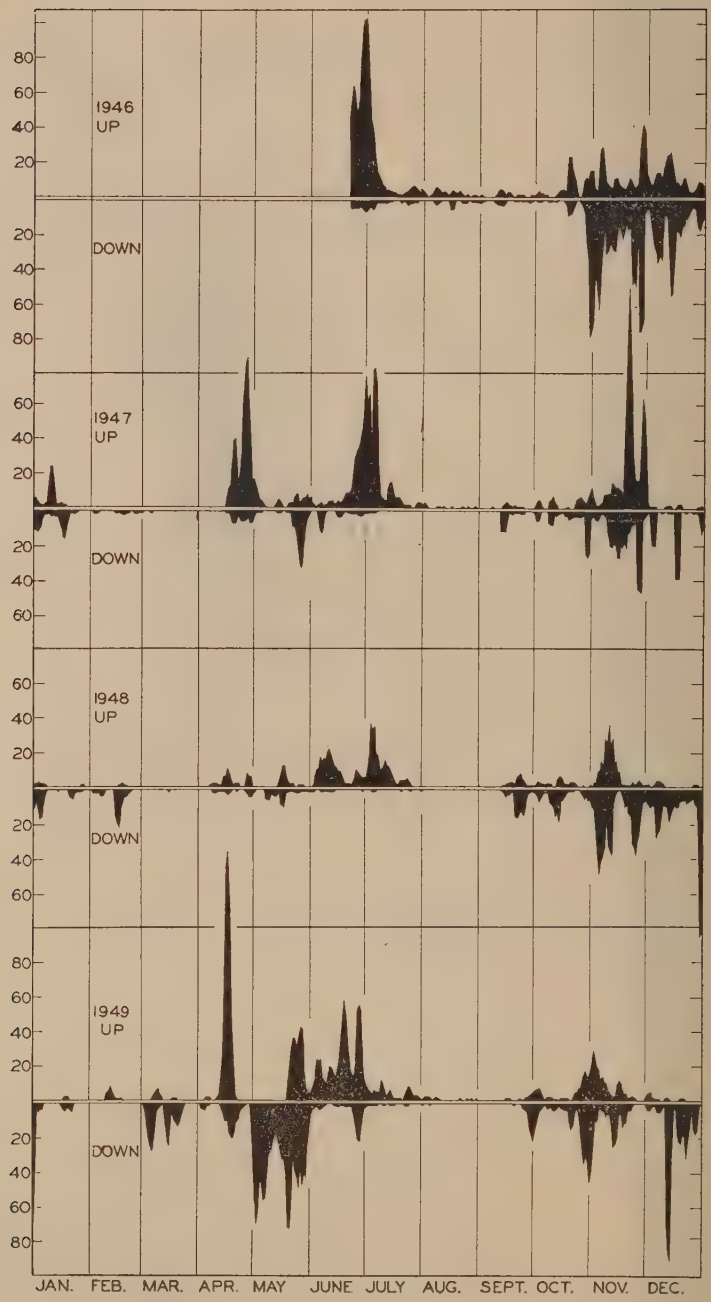

Figure 1.

Migration of trout into and out of Ellerslie Brook in numbers per day.

Of the second category of trout movements, which appear to occur in addition to rather than in place of the more regular movements just discussed, the most noteworthy are those upward in April, 1947 and 1949, and the extensive downward run in May, 1949. The relatively small downward runs in February, 1948, and March, 1949, are also of particular interest in demonstrating activity of trout while the brook is covered with ice and snow. But for these instances, however, few trout apparently move at that season. August and early September are also periods of little migrating activity.

It is not intended in this report to inquire into the possible causes of the observed trout movements as the pertinent data have been incompletely analysed. Suffice it to report that a number of factors—height of water, change in water level, temperature of water, size and maturity of the trout—are involved.

Relation to Anglers' Catches

It is shown in Table I that the anglers' catch for 1949 was approximately 100 per cent greater than that in either 1947 or 1948, for which two years the angling record was quite constant with respect both to the number of trout captured and the rate at which they were taken. Tagged trout, that is trout which have moved through the fish trap, were responsible for much of the increased 1949 catch. Thus, the improved angling was correlated with the greater migratory activity of the trout in April, May and June, 1949, and also, so far as the records of the proportions tagged have been analysed, with a larger number of trout entering Ellerslie Brook from other areas. The possibility of a greater take of Ellerslie stocks is not, however, to be overlooked.

In the programme at Ellerslie Brook one of the more important criteria by which the effects of forming a pond upon the trout stock were to be gauged was the anglers' catch from year to year as revealed by the annual creel census. It was planned to study the movements of the trout from 1946 to 1950 before building a dam. By 1950 it was anticipated that a "normal" level for the catch without a pond would be established. Certainly the marked difference that was found between the catches of 1948 and 1949 was not expected, and has necessitated a continuance of the study without pond formation to ascertain whether the catch for 1949 was unduly high and that for 1947 and 1948 more "normal". The findings at Ellerslie Brook have illustrated clearly the difficulty of establishing a reasonably constant control level for comparative measurements of fish production in nature, in this case the yield of trout to anglers from a small stream.

Table I.

Yield of trout to anglers, Ellerslie Brook.

—	1947	1948	1949
Tagged	501	502	1,246
Untagged	640	553	756
Totals	1,141	1,055	2,002
Number per rod-hour	1.5	1.5	1.7

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OBSERVATIONS ON TROLL-CAUGHT SALMON OF THE WEST COAST OF VANCOUVER ISLAND, 1949

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OBSERVATIONS ON TROLL-CAUGHT SALMON OF THE WEST COAST OF VANCOUVER ISLAND, 1949

INTRODUCTION

The salmon troll fishery of the west coast of Vancouver Island was investigated in 1949 by the Fisheries Research Board of Canada through the charter of a commercial trolling vessel. Fishing was carried out on the offshore banks in the general vicinity of Amphitrite Point (referred to in this account as "Ucluelet area") from May 10th to July 2nd and on August 3rd and 4th; and in or near Quatsino Sound from July 5th to August 1st.

Ordinary commercial fishing practices were employed except that barbs were removed or rendered inoperative on the gear used. In the opinion of the operators this did not significantly affect the number of fish secured. Six lines were used, with 3 to 5 lures on each line.

All fish caught, with minor exceptions, were measured for length. Scale samples were taken from those tagged. For untagged fish, the length, round and dressed weight, sex and color were recorded.

Acknowledgments are due to Mr. P. W. Martin, owner and operator of the "Wandelaine", whose practical fishing experience and local knowledge were combined with biological training, and to Mr. H. W. Spencer who, in addition to taking part in most of the field operations, was responsible for tabulating many of the data obtained.

CHINOOK SALMON

Size Composition

A total of 1,204 chinook salmon was taken during the indicated period.

On the basis of length measurements, these fish were divided into groups representing approximately the weight-categories recognized by the industry.

TABLE 1. PERCENTAGE SIZE COMPOSITION OF CHINOOK CATCH

Category		1	2	3	4	Number of Individuals
Fork Length		Below 24½"	24½" 28½"	29" 31"	Above 31"	
Approximate Dressed Weight		Below 5 lbs.	5–10 lbs.	10–14 lbs.	Above 14 lbs.	
	Week ending					
Ucluelet	May 13	34.4	59.4	3.1	3.1	32
	20	34.2	49.8	8.7	7.3	231
	27	17.3	60.0	16.0	6.7	75
	June 3	23.6	47.1	15.9	13.4	157
	10	20.0	38.0	22.0	20.0	50
	17	29.6	46.5	8.9	15.0	179
	24	15.4	46.1	21.9	16.6	187
	July 1	5.7	54.6	17.0	22.7	106
Quatsino	July 8	2.1	16.6	35.4	45.9	48
	15	0.0	9.5	19.0	71.5	21
	22	7.7	7.7	23.1	61.5	13
	29	6.9	10.3	31.0	51.8	29
Mainly Ucluelet	Aug. 5	8.8	32.3	19.0	39.9	68

Age Composition

Scale samples were taken from those fish which were tagged. Seven hundred thirty-seven of these samples were considered to be readable and the distribution of these is recorded in Table 2.

The subscript "2" indicates that the fish had spent a full year in fresh water before going to sea.

Table 2. Age Composition of Tagged Chinook Salmon

Year of life	2_1	3_1	3_2	4_1	4_2	5_1	5_2
Number of individuals	23	600	16	67	28	0	3
Percentage	3.1	81.4	2.2	9.1	3.8	0	0.4

It is evident that the scale samples were taken almost entirely from fish in their third and fourth years of life, with an insignificant number in their second and fifth years. The percentages recorded, however, cannot be applied to the total catch, since the fish from which the scale samples were taken were to some extent selected from the smaller size categories. Examination of the recorded lengths of all fish suggests that third year chinooks constituted 65% to 70% of the total number caught. In the Quatsino catches, fourth-year fish probably predominated.

The relation between age and size, as revealed by the sampled fish, is expressed in Table 3.

Table 3. Age and Size of Chinook Salmon, by Months of Capture

Age group	2_1	3_1	3_2	4_1	4_2	5_2
May:						
Number	11	235	4	21	9	.....
Length range	12.25–19.0	18–31	18–26	23.5–34	22–29.5	.....
Average	15.5	24.4	21.6	29.2	26.6	.....
June:						
Number	9	311	10	33	14	3
Length range	12.25–22	19.5–31	18.5–27.5	25.5–35	23–33.5	31.5–34
Average	17.0	25.8	23.0	31.5	28.7	32.0
July:						
Number	1	37	.....	11	4	.....
Length range	.....	23 33	.....	27–35	26–31	.....
Average	(18.0)	27.7	.....	31.2	28.1	.....

Tagging

Table 4 shows the number of fish tagged during 1949 and the total number of recoveries up to September 15, 1950.

Table 4. Chinook Salmon Tagged and Recovered

Area	Tags Applied	Tags Recovered	Percent Recovered
Ucluelet	772	57	7.38
Quatsino	45	11	24.40
All	817	68	8.32

The difference between the percentage recovered from the Ucluelet and Quatsino taggings is striking. Other differences in recovery rates become apparent, however, when the fish are grouped according to size categories and year of recapture, irrespective of the tagging area (see Table 5).

The larger fish have evidently yielded higher returns and the discrepancy between Ucluelet and Quatsino recoveries may be due in part to the larger average size of the fish tagged in the latter area. There is a possibility that further returns of tags may necessitate some revision of these

figures. Tag returns in 1951 are not expected to be numerous in view of the apparent scarcity of fifth year fish in the commercial catch.

TABLE 5. RECOVERIES OF TAGGED CHINOOK SALMON ACCORDING TO SIZE OF FISH WHEN TAGGED AND YEAR OF RECOVERY

Size Category (see Table 1)	1	2	3	4
Number of fish tagged	256	424	91	38
Percent distribution of fish tagged	31.6	52.4	11.2	4.7
Number of fish recovered in 1949	7	14	10	7
Percent distribution of 1949 recoveries	18.4	36.8	26.4	18.4
Number of fish recovered in 1950	1	26	3	0
Percent distribution of 1950 recoveries	3.3	86.7	10.0	0
Percent distribution of all recoveries	11.8	58.8	19.1	10.3
Percent recovery of fish tagged	3.1	9.1	14.3	18.4

The increased number of recoveries in 1950 of fish which were placed in category 2 at the time of tagging, demonstrates the immaturity of a large portion of the original catch and the increased susceptibility to capture with increasing size or age.

The recoveries, grouped according to age of fish when tagged, were as follows:

TABLE 6. RECOVERIES OF TAGGED CHINOOK, BY AGE WHEN TAGGED AND SEASON OF RECAPTURE

Age, 1949	2	3	4	Doubtful
Number recovered 1949	0	23	11	4
Number recovered 1950	0	28	1	1

Distribution of Recoveries

The localities from which tagged fish were recovered are shown in Figure 1.

A striking feature of the Ucluelet fish is the high proportion of recoveries made in or near the area in which the fish were tagged. These recaptures took place after an interval varying from 16 to 457 days, so that in each case there was plenty of time for the salmon to move elsewhere. This result, coupled with the evidence of the presence of large numbers of immature fish, increasing in average size during the fishing season, suggests strongly that the banks in this area provide feeding grounds for chinooks over a prolonged period of their ocean existence.

Other recoveries of Ucluelet chinooks show fish proceeding both into Juan de Fuca Strait and to the Columbia River. The extreme range of recorded dispersal is from Graham Island (about 450 miles north-west of the tagging area) to Point Ano Nuevo, California (some 900 miles south of Ucluelet).

The Quatsino fish, on the other hand, have yielded no recoveries from the tagging area. This fact, together with the apparent scarcity of small salmon (see Table 1) is taken as an indication that chinooks caught in this district are mainly migrating fish.

Recoveries from Quatsino taggings again show fish traveling both to Juan de Fuca Strait and the Columbia River.

Comments

The conclusions and inferences drawn from the available data may be summarized as follows:

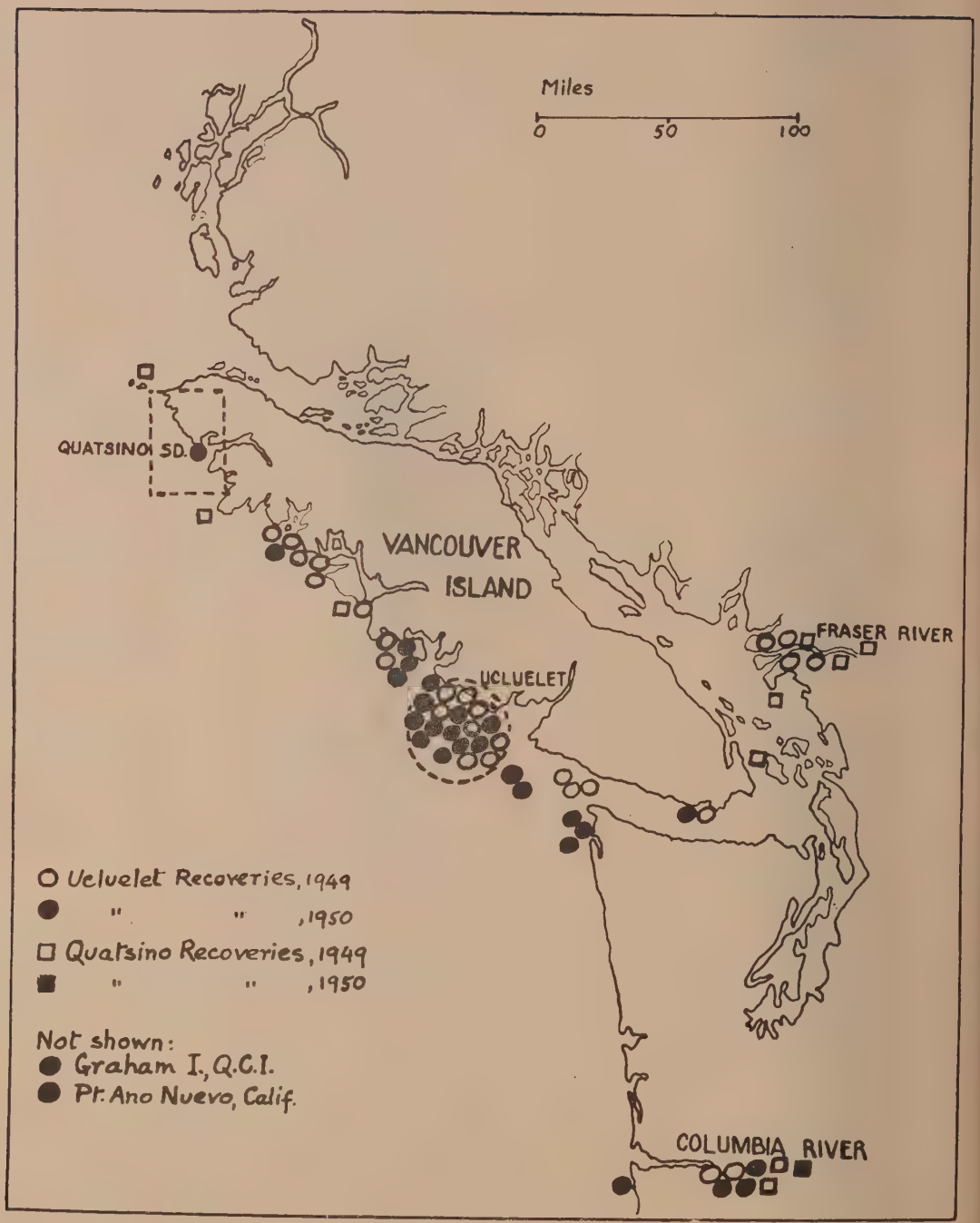

FIGURE 1. Chinook Salmon taggings and recoveries.

1. The chinooks available in 1949 in the Amphitrite Point-Tofino offshore area were predominantly fish in their third year of life, i.e., of the 1946 year class. In the Quatsino Sound area, older fish predominated.

2. Most of the third-year fish available would not have matured until the following year. Chinooks, at least in some areas, are therefore subject to exploitation during at least two full fishing seasons. (The other species of Pacific salmon are, for the most part, exploited during only one season of their life cycle.)

3. The overall percentage return of tags does not demonstrate a high rate of exploitation. Hasty conclusions to this effect should be avoided, however, in view of the following considerations: a) The fish had already become available for capture before being tagged—in the case of the fourth year fish for a period of at least a year. (b) Loss of tags, non-return of tags and differential mortality of tagged fish may have affected the record to a considerable degree, especially in view of the long period over which fish are available to the fishery. (c) Considerable differences are apparent in the tag returns for fish of different sizes, ages and localities. (d) The majority of the fish were tagged in an area which may be somewhat peculiar in respect to the age and size composition of the available fish.

4. The banks situated offshore from the Amphitrite Point-Tofino section of coastline appear to provide feeding grounds during a prolonged period for chinook salmon from divers freshwater areas. On the other hand, the Quatsino Sound area appears to depend largely on migrating fish.

5. The dressed weight of 14 lbs. or above which is recognized by the industry for "mild-cure" purposes practically limits this product to fourth-year, or older, fish. The records of fishing companies may therefore give useful indications of the relative strength of year-classes in different seasons.

The present British Columbia minimum weight of 2½ lbs. dressed weight excludes second-year fish from the catch. To effectively exclude third-year fish throughout the season (on a size basis) it would be necessary to raise the minimum dressed weight to at least 10 lbs. or 12 lbs., representing a fork length of 28½ to 30 inches.

6. If the existence and location of definite long-period feeding areas can be confirmed or established, recognition of these might well enter into conservation regulations or practices. If, for example, it should be found desirable to protect immature fish in order to permit further growth before capture, the closing of such areas might be more effective than a general upward revision of the size-limit. Because of the growth which takes place during the course of a fishing season and the varying sizes at which chinooks mature, any fixed size- or weight-limit can only effect a very rough segregation. If, as seems possible from these taggings, fish tend to remain in certain areas until growth is nearly completed, they would become available at whatever size they began to move towards the spawning grounds.

SILVER SALMON

In all, approximately 700 fish were caught. Of this total, only 51 were taken in the May and June operations based on Uchulet. The remainder, with three exceptions, were caught in the Quatsino area.

Some deviation from a strictly commercial sampling of the catch may have been introduced by the fact that at times of heavy fishing the exigencies of tagging prevented full exploitation of the availability of fish.

Size Composition.

Marked increase in the average size of fish was apparent during the course of the season (see Table 7).

Table 7. Length-Frequencies of Silver Salmon, by Month of Capture

Length (fork)	May	June	July	Totals
18″ and under	4			4
19″ and under	6	1	1	8
20″ and under	4	2	5	11
21″ and under	4	2	11	17
22″ and under	3	3	17	23
23″ and under	4	6	33	43
24″ and under	1	2	62	65
25″ and under		2	162	164
26″ and under		2	160	162
27″ and under			112	112
28″ and under			58	58
29″ and under		1	18	19
30″ and under			1	1
31″ and under			2	2
Totals	26	21	642	689

Tagging

Table 8. Silver Salmon Tagged and Recovered, 1949

Area	Period	Number Tagged	Number Recovered	Percent Recovered
Ucluelet	May 12–July 2	40	5	12.5
Quatsino	July 5–Aug. 1	470	38	8.1
All		510	43	8.4

Since this species tends to struggle violently when on the hook and in the hand, the problem of returning tagged fish to the water in good condition is more serious than in the case of the chinook. In the majority of instances, the condition of each fish released was recorded as "good", "fair" or "poor". On this basis, the recoveries were as follows:

Table 9. Recovery of Silver Salmon Tags in Relation to Condition of Fish When Tagged

Condition	"Good"	"Fair"	"Poor"	Unrecorded
Number of fish tagged	336	61	31	82
Number of fish recovered	30	3	1	10
Percent recovered	8.9	4.9	3.2	12.2

While the proportion of recoveries appears to be less in the categories representing a less favourable condition, the relatively high recovery rate for the unrecorded fish indicates that the percentages cannot be applied rigidly.

Distribution of Recoveries

The time-interval between tagging and recapture varied from 6 to 115 days.

While the recovered tags did not show as extreme a north-south range as those of the chinooks, a greater dispersal was evident within the waters of central and southern British Columbia and northern Washington, indicating that silver salmon spawning in many freshwater areas are closely associated during at least part of their ocean existence. The collective importance of numerous small rivers and streams in contributing to the offshore troll fishery is evidenced. No recoveries were reported from the Columbia River (see Figure 2).

FIGURE 2. Silver Salmon taggings and recoveries.

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Mechanical Refrigeration For Railway Cars

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By O. C. YOUNG*

IN the April 1951 issue of Canadian Fisherman, an article on the "Overhead Bunker Refrigerator Cars on Canadian Railways" by M. W. Thistle and W. H. Cook of the National Research Council Laboratories, Ottawa, reviewed the transport problems confronting the shippers of frozen foods in Canada, and it was explained that those problems that were considered to require investigation and research were discussed at meetings of the Sub-Committee on Engineering of the Canadian Committee on Food Preservation. Among other considerations the possibility of using mechanical refrigeration on railway cars was deemed to be of sufficient importance to warrant investigation. Responsibility for this work was assigned to the Fisheries Research Board in cooperation with the Canadian railway companies, while the National Research Council investigated means of approaching the target temperature of 0°F. more closely in overhead bunker refrigerator cars through modifications, and the use of mixtures of salts with ice. This present article will give a brief review of the work done by the collaborating bodies with a mechanical car in Canada.

Previous Work Reviewed

Before making a decision on the particular type of mechanical equipment with which to experiment, a review of previously tried devices was made and these included not only those tried out on railways but those being used on trucks also. The outcome of this study was the selection of the "packaged" type of equipment. That is, equipment that is self contained in one or more packages for quick replacement or accessibility for repairs. Trucks were having considerable success with such units, and though it was realized that railway usage could be rougher than truck usage because of the lack of rubber tires and through shock due to shunting, the advantages of composite units seemed to outweigh the foreseeable disadvantages. The system investigated, therefore, comprised two units, each complete in a single "package", apart from batteries and fuel tanks.

Each unit consisted of a 4-cylinder gasoline engine driving directly a 6-cylinder freon-12 compressor, and, through V-belts, two fans: one for the engine cooling system and the refrigerant air condenser, and the other for the air circulation within the car and through the evaporator. In addition a finned coil evaporator and a similar condenser along with the necessary valves and automatic devices made up each unit. Figure 1, shows diagramatically the arrangement of the two experimental units in place at either side of one end of the experimental car. Figure 2, shows how a unit could be quickly taken out of the car on a sliding device equipped with metal rollers and fitted into the car.

In order to fulfil the general purposes to which the standard Canadian refrigerator car is subjected, the mechanical units were equipped to heat as well as to cool the carload, applying what

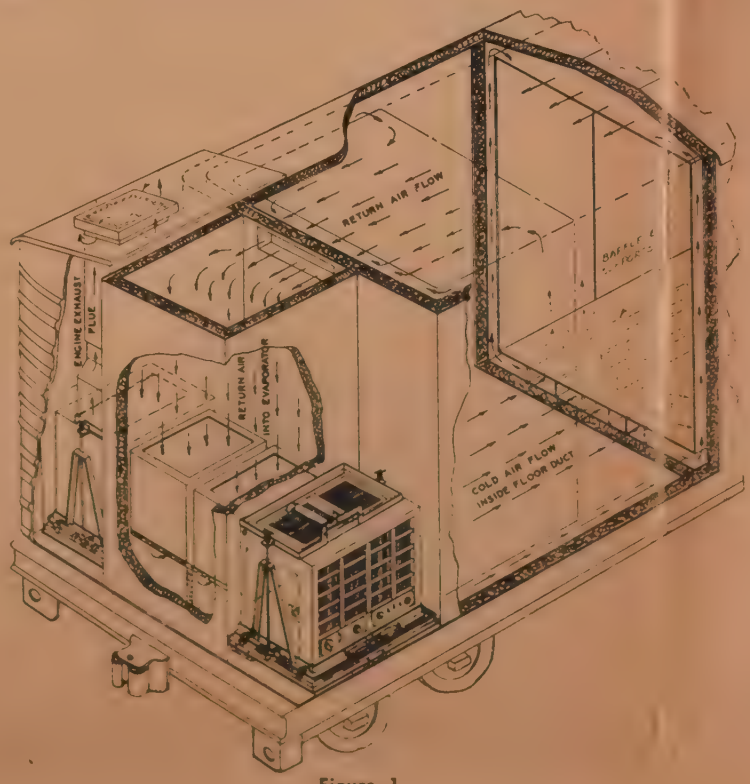

Figure 1.

*Mr O. C. Young, Scientific Assistant, to the Chairman, Fisheries Research Board of Canada, is well known for his research and experimental work in the field of food preservation and particularly fish products.

is popularly called the "heat pump" principle.

The first test conducted with the experimental equipment was made to determine the security of the sliding and clamping devices for the units. For this purpose the Canadian National Railways supplied a Savage Impact Register by means of which a chart showing the magnitude of the shocks imparted was obtained. Mechanical shocks were imparted to the experimental car by yard tests, both by "slacking" it with an engine moving at different speeds, or by letting it "hit" a stationary string of cars while moving at different speeds. The Impact Register indicated that impacts up to the "wrecking" point (10-11 miles per hour) were imparted to the car, with no evident affect on the equipment or its operation.

Figure 2.

Two-Year Experiment

During the course of two years of experimentation with the experimental car, ten road tests were conducted most of which involved trips practically across the continent. Six of these tests were under "freezing" operation wherein sub-zero (F) temperatures were maintained within the car; One test was under cooling (to 32°F.) operation; and the remaining three were under heating operations in the winter time.

Four of the six tests under freezing operation were accompanied by observers, and temperature and other observations at approximately three hour intervals were taken during these tests. Figure 3, shows graphically the temperature records obtained during one of these accompanied road tests. The remaining two tests under freezing operation were unaccompanied. In these latter tests the temperature regulating devices were set as in the accompanied tests, and essentially the same results were obtained, as indicated by observations made by railway employees along the routes. These freezing tests varied in duration from 4½ to 12 days and though from time to time weaknesses in elements here and there were revealed, these were all of a minor nature and were corrected through simple modifications. It was concluded from these freezing tests that the equipment had ample refrigeration capacity for this type of traffic in Canada. For not only were sub-zero temperatures (F.) maintained in the car during all these tests, but in addition, in those cases in which the commo ties loaded were 10°o to 15° above that at which the car te perature was to be maintained, temperature of the load was r idly reduced to the desired deg in the early stages of the tests.

The three road tests conduc under heating operations t place during winter conditio Figure 4, shows graphically temperature record obtained d ing one of these tests. This p ticular test was conducted w canned foods which tolerate rather wide range of temperatu without significant effects quality. In order to test the he ing capacity of the equipment temperature regulator was set 50°F. and the test was plann for a time when the weather wo likely be cold. Fortunately

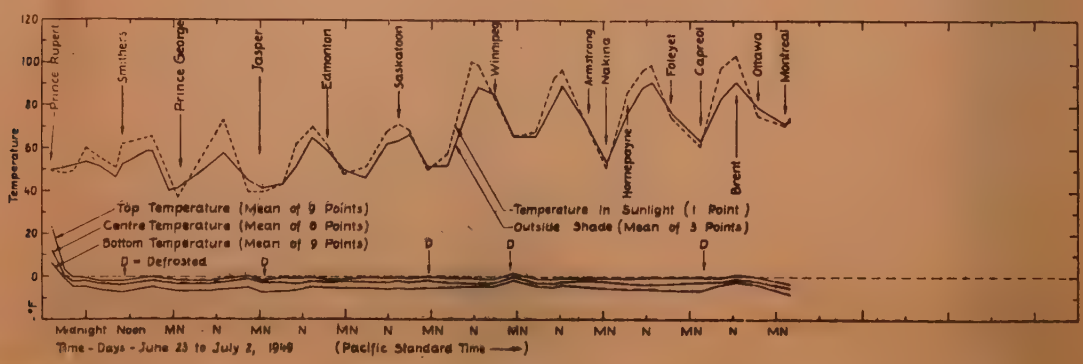

Figure 3.

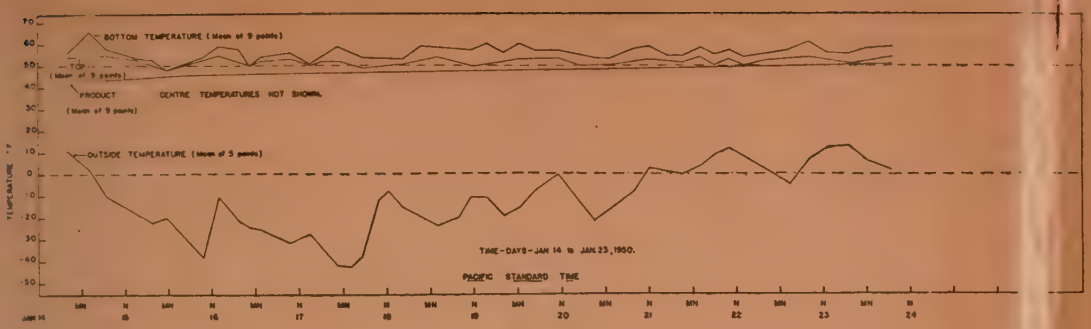

Figure 4.

tremely cold weather did prevail for the first five days of the test as will be noticed by the graphs, nevertheless, only one of the two units was required during the test and it operated only about one-third of the time during the coldest periods. It was concluded, therefore, that the system had ample heating capacity for Canadian winter conditions.

"Field Heat" Test

The final test with the experimental car was conducted at the request of the Canadian National Railways and was for the purpose of observing the performance of the mechanical system when coping with a load of fresh fruits coming directly from orchards and with the "field heat" still present. Calculations indicate that the cooling of such a load from say 75° to 32°F. in 12 hours, imposes a greater refrigeration demand than the mere holding at -5°F. of a frozen load that has had its temperature already reduced to the holding level. To cool the fruit requires the extraction of heat of respiration as well as specific heat, and the action is complicated by considerable quantities of water vapour given off by the fruit and which sublimes as "frost" on the cooling surfaces. Each pound of frost that collects on the cooling surfaces represents the transfer of over eleven hundred heat units (BTU) and because the frost collects in a bulky form it retards air circulation and greatly reduces the efficiency of cooling surfaces on which it accumulates.

In coping with a 21,000 lb. load of plums and pears, the experimental equipment demonstrated that it had ample cooling capacity. Indeed the capacity was more than could be employed continuously, for portions of the load would have been damaged by freezing if both mechanical units had been permitted to operate and the temperature regulator had not been altered from time to time to take care of the varying heat load.

The extremely rapid cooling resulted in wide temperature differences within the load. These differences could be reduced in periods of high refrigeration demands within the car by having cooled air circulate *through* the load, but this was not provided in this test. Thus it was demonstrated that the system would require modification to provide positive air circulation through the load for shipments consisting of fresh fruits or vegetables not previously precooled. Furthermore, the position of the sensitive element of the temperature regulator was shown to be important; for while, with frozen loads its location in the return air stream proved satisfactory, for unfrozen loads, such as in this final test, it should be in the outlet air stream from the machines in order to avoid freezing of sensitive commodities.

Mechanical Refrigeration Could Provide Desired Conditions

The ten extended road tests conducted in a period of about 2 years with the experimental car demonstrated that mechanical refrigeration equipment of reasonable size and weight could provide the desired conditions for the various perishable commodities normally shipped in refrigerator cars in Canada, and could withstand normal railway handling. However, the particular equipment employed in the experiments was not acceptable to the two large Canadian railway companies for general use mainly because of the fuel employed. Gasoline was considered to be too hazardous and is actually not permissible according to insurance regulations of one of the companies. In the light of available knowledge representatives of the Canadian Railway Companies have drawn up rather complete specifications for a system that will likely fulfil requirements in Canada, and in these specifications power for the equipment is to be supplied by diesel engines.

To Try Modified Diesel Units

Units are not available to meet the specifications just referred to. However, several experimental diesel units have been tested in the United States recently with some success, and the Canadian companies have intimated that they are planning to procure units of the diesel type which will be modified to conform with the Canadian specifications more closely. In view of the present metal shortages it is not likely that the railways' plans can be carried out immediately; therefore, tests with the modified equipment are not anticipated in 1951.

In the light of all of the results with recently evolved mechanical equipment for refrigerator cars it seems altogether likely that diesel powered units will be worked out to be satisfactory in Canada from the technical viewpoint. But because there is not agreement in the studies of the costs with the meagre data so far available, the economic feasibility of these systems remains in doubt. However, mechanical systems are finding their way into the passenger car

cooling field, and if units or parts of units can be standardized sufficiently to be applied as well in freight and express refrigerator cars, the economic feasibility of mechanical cooling on railways will have definite possibilities.

Any changeover, however, will be slow, and will most likely be dependent upon the increased development of the freezing method of preserving perishable foods. The Canadian Railways are now using and are continuing to improve the overhead system of cooling refrigerator cars already described in this journal, and this piece of equipment is doing a splendid protective job for all but frozen commodities in the hottest summer weather. Because the proportion of frozen commodities shipped in Canada is small in relation to the total quantity of perishable traffic handled in Canada, relatively few refrigerator cars will handle this frozen material. However, through improvements in mechanical refrigeration and through experience and resultant economies induced by flexibility, standardization and interchangeability of equipment, it is possible that mechanical cooling and heating of cars will come more into general use. One need not necessarily become prophetic, therefore, to observe that if mechanical systems of cooling and heating have lasting merit they will certainly be applied. There is so much interest directed on railway refrigerator cars all over the world that rapid advances are to be expected. The experimental work being carried on in Canada, the United States, and Europe, will certainly reveal whether mechanically refrigerated railway cars are economically as well as technically feasible. The economic phase of the studies involves so many factors that are difficult to assess, however, particularly those related to operating and maintenance techniques, that we will not know for several years whether the mechanically refrigerated railway car is really the car of tomorrow.

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PROTEIN DENATURATION IN FROZEN AND STORED FISH[a]

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(Manuscript received May 28, 1951)

Study of the per capita consumption of frozen fish in different areas of Canada shows that it is not a popular food. Particularly in the inland centers of Ontario and Quebec where fresh and frozen fish compete side by side, the preference for fresh fish is well shown. This is true in spite of the difficulty in shipping fresh fillets this distance in reasonably fresh condition. For example, in Toronto in 1947 the per capita consumption of fresh Atlantic cod fillets was 1.4 lbs., whereas frozen cod fillets totalled only 0.34 lb. Similarly, in the city of Montreal, the corresponding consumption was 2.2 and 0.37 lbs., respectively. In the province of Nova Scotia, close to the supply of both products, the figures were 0.74 lb. and 0.50 lb., respectively *(10)*. It is evident that there exists a very decided preference for the fresh over the frozen product.

Several laboratories including our own have been working on this problem. There is ample evidence that the act of freezing itself does not account for the lowering in quality, except in a few species of minor importance *(12)*. In fact, the quality may often be improved immediately after freezing *(11)*.

Young *(11)*, by means of taste panels on frozen and fresh halibut, showed that freshly frozen samples were somewhat firmer and drier than the unfrozen ones and were preferred by many people. While the appearance of rapidly frozen samples stored at 14°F.(—10°C.) was superior to that of slow frozen samples stored at —13°F.(—25°C.), the taste panel tests were very definitely in disagreement. With Pacific salmon also *(12)* it was found that after an initial period, the temperature of storage became more important than the rate of freezing.

Notevarp and Heen *(4)* have studied the effects of freezing rate, storage temperature, and freshness of raw material on the quality of frozen cod and herring. They showed that changes in freezing rates up to where 8 hours are required for freezing have almost no effect on the product. Of course, very slow freezing is detrimental, but storage temperature rapidly becomes more important than the rate of freezing. The state of preservation of the fish previous to freezing greatly affected the quality in frozen storage. At 16°F.(—9°C.), fresh cod remained acceptable as judged by a taste panel for 2.5 to 3.0 months; frozen after 3 days of prestorage in ice, it kept for about 2 months; and after 8 days in ice it kept for only about 1 month. At —4°F.(—20°C.), fresh cod kept well for 8 to 9 months; after 3 days in ice, about 5 months; and after prestorage for 8 days in ice, about 3 to 4 months.

[a] Presented at the Eleventh Annual Meeting of the IFT, New York, N. Y., June 19, 1951.

Reay *(5)* summarizes experiments carried out at the Torry Fisheries Research Station in Britain on freezing of white fish, and concludes that freshness of fish and temperature of storage are most important, the rate of freezing being a minor factor.

In our laboratory, we have carried out several experiments using taste panels to measure the deterioration in quality of Atlantic cod, haddock, and Atlantic halibut in frozen storage.

In the first series of tests, it was shown that haddock had a keeping quality definitely superior to cod, and it was found that the temperature of storage soon became much more important than the freezing rate. While large ice crystals developed on slow freezing and gave the fish a poor appearance, this had little effect on the taste panel rating. Our conclusions therefore agree with Young *(11)*, Notevarp and Heen *(4)*, and Reay *(5)* that the rate of freezing is not as important as it was considered formerly. Prebrining the fish to prevent loss of drip on thawing overcomes most of the ill effects of moderately slow freezing, although some sacrifice of appearance is made.

In the second series, strictly fresh cod were used. The samples were rapidly frozen in 1-lb. flat cans to avoid the effects of surface desiccation. Two storage temperatures of 10°F.(—12°C.) and —10°F.(—23°C.) were used. The fish samples were baked at 500°F.(260°C.) for 16 minutes and served without condiments along with a fresh control. Three panels of about 8 judges were used for each sampling. The samples were graded on the basis of texture, odor, and taste, and were given ratings of 0 to 5.

At 10°F.(—12°C.) the samples became inferior to the control in three weeks of storage and were unacceptable after about five months (Figure 1). The samples stored at —10°F.(—23°C.) were superior to the control for about 6 weeks, being slightly more tender, and equalled the control up to about 5 months. They became unpalatable at 10 to 11 months.

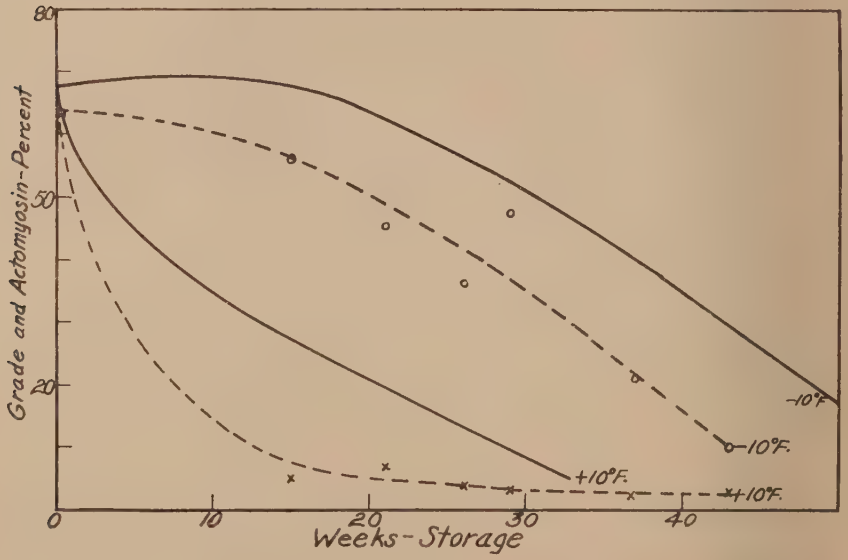

FIGURE 1. Taste panel grades (solid lines), expressed as percent of maximum grade, and soluble actomyosin (dotted lines), expressed as percent total protein, in frozen cod fillets stored at 10°F.(—12°C.) and at —10°F.(—23°C.).

The important changes occurring were the development of tastelessness and loss of tenderness, finally proceeding to development of toughness and of off-flavors and odors.

Halibut was examined after storage at temperatures of 10°F.(—12°C.), 0°F.(—18°C.), and —10°F.(—23°C.). Here again, the texture change from tender to tough and development of objectionable off-flavors were the major factors in the taste panel assessments. Atlantic halibut in sealed 1-lb. cans kept satisfactorily for 18 months at —10°F. (—23°C.) and at 0°F.(—18°C.) as shown in Figure 2. At 10°F.(—12°C.) the samples were rejected after about 8 months. There was insufficient difference between storage temperature of 0°F.(—18°C.) and —10°F.(—23°C.) to justify the use of the lower temperature.

Two things are evident from this work: 1, that off-flavors suggestive of fat spoilage develop on frozen storage even in the non-fatty fish such as cod and haddock; and 2, the lowering of grade parallels the loss of tenderness and the development of toughness.

In the cod stored for 9 months, it was found that the fat contained about 72% free fatty acids calculated as oleic acid. Similarly, in the halibut there was a development of free fatty acids and an increase in peroxide values on storage. Thus, fat spoilage definitely cannot be ruled out in the frozen fish in the low fat species such as cod and haddock.

The second finding, the development of toughness, is related to the denaturation of the proteins. This has been studied extensively.

Reay and Kuchel *(6)*, applying to fish the procedure used by Bate-Smith *(7)* in his study of the proteins of rabbit muscle, found a decrease in the solubility of the proteins extracted by salt solutions after frozen storage. Dyer, French, and Snow *(3)* investigated this further and showed that it was the actomyosin fraction which was denatured, the non-actomyosin fraction remaining unchanged except after very long storage. The protein fractions present were also determined using a method by which 90 to 95% of the total protein was dispersed in 5% sodium chloride solution. Actomyosin was found to comprise 75 to 80% of the protein. Extraction of the soluble protein, followed by an estimation of the actomyosin of the solution then gives us a measure of the degree of protein denaturation.

The results obtained in the above taste panel experiments are shown in Figure 1 (dotted lines) and Figure 2. It is seen that in all cases the soluble actomyosin decreases faster than the taste panel grades. In the case of the cod fillets, the soluble actomyosin has decreased almost to zero by the time the taste panel had rejected the samples as unacceptable. It is thus seen that the actomyosin solubility appears to parallel and anticipate the taste panel rating and provides a quantitative measure of the quality of a particular sample of fish. Of course, it is only one of the variables in the complex function of consumer acceptability, but it is an important one and one which in general parallels the other changes. Work is now proceeding in testing this method of assessing and predicting quality of frozen fillets.

Considerably more work has been carried out on the denaturation of actomyosin systems both in situ and in isolated form. It has been already

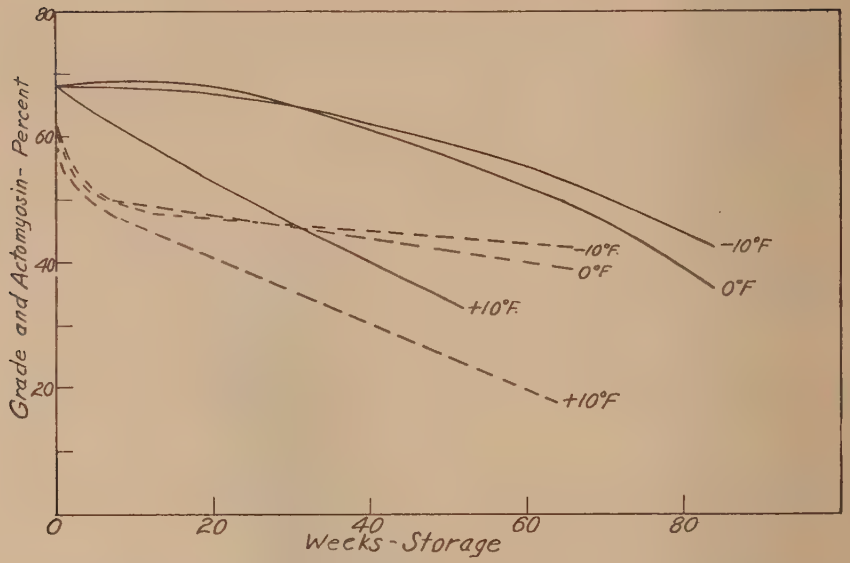

FIGURE 2. Taste panel grades (solid lines), expressed as percent of maximum grade, and soluble actomyosin (dotted lines), expressed as percent total protein, in frozen Atlantic halibut stored at 10°F.(—12°C.), 0°F.(—18°C.), and —10°F.(—23°C.).

established, for instance, that surface dehydration almost completely denatures the proteins on the surface.

When actomyosin is extracted in salt solution, it may be precipitated by diluting with cold water to a concentration of about 0.5% sodium chloride. On standing, the actomyosin may be centrifuged off as a gel which still contains about 99% water.

When gels of actomyosin are frozen, they are almost completely denatured. But not so with sols. Here little or no denaturation occurs, depending on the salt present and other conditions. In the muscle cell, the actomyosin exists mostly in the form of a sol and thus the denaturation of the actomyosin in situ parallels the sol denaturation rather than that of the gel.

It was found *(8)* when sols of actomyosin were frozen in the presence of various salts, that denaturation did not occur as long as the temperature was kept above the eutectic point. When this was passed, however, rapid denaturation occurred, presumably because the sol was now converted to the gel form.

Since we do not know the concentration of each of the various salts in fish muscle, or their eutectic points, we cannot say whether there is a temperature below which denaturation would occur. Furthermore, different species may vary in this respect.

Another line of investigation which has been pursued is the effect of salt on actomyosin. Duerr and Dyer *(2)* have shown that when cod fillets are salted in saturated brine there is a definite concentration of salt (about 8 to 10%) in the fillet at which denaturation occurs. As the salt concentration reaches this level, the actomyosin is suddenly denatured, the water held by the protein micelles is released, and diffuses into the more saturated brine outside. Thus, a rapid loss of water occurs at this point.

This was carried further with isolated actomyosin sols and it was shown that the salt concentration necessary for denaturation decreased with increasing concentration of protein such that a supersaturated sol as present in fish muscle would be denatured at about 10% salt. Determination of moisture contents of the denatured gels showed that the moisture content decreased rapidly with increasing salt content and it would appear that a competition for water by the myosin and the salt solution exists.

As the salt penetrates the gel, the salt concentration rises and in the region of 3 to 8% sodium chloride concentration the myosin swells strongly. But when the salt concentration reaches about 10% the swelling is strongly reduced, the actomyosin releases sufficient of its water to disrupt the native configuration of its highly organized micellar structure and denaturation occurs. This same process is related to the denaturation occurring on freezing which may partially be considered as a removal of water as ice crystals.

The moisture contents of gels denatured by freezing and by salt were determined. Freeze-denatured gel was found to contain 95.0% water whereas the native gel contained 98.7%. Salt denatured gels varied from 88 to 94% depending on the salt concentration used to denature the gel.

DISCUSSION

Of course, one of the uncertainties in this work is a lack of knowledge of what protein fractions are actually present. Recent work on actomyosin by Szent-Györgyi *(9)* and Dubuisson *(1)* emphasizes the involved chemistry of the muscle protein complex.

For instance, lipids, fatty acids, nucleotide compounds, or even carbohydrates may protect or modify the properties of actomyosin. The understanding of these questions is just beginning to be unravelled, and nobody can say where the future lies. It seems quite within the realm of probability that we may be able to inhibit, at least partially, the denaturation in frozen products.

Other problems which we should consider in dealing with frozen fish products are, of course, the engineering aspects of the efficient design of freezing apparatus and of temperature maintenance during storage. Advances are being constantly made and as an example one might mention the development of refrigerated railway cars and trucks capable of maintaining sustained low temperatures.

SUMMARY

The above discussion suggests certain points to be kept in mind in the freezing and storage of fish. Fresh material should be used and reasonably fast freezing should be applied. Storage should be at 0°F.(—18°C.) or below. Desiccation should be prevented and the storage period should be limited according to the specific requirement of the species. Low refrigeration temperatures should be maintained throughout the merchandizing chain.

Attention to these factors will reduce the deterioration in quality of frozen fish products occurring on storage. There will be less protein denaturation, and therefore less toughening of the texture and off-flavor development will be minimized as far as our present knowledge will permit. Even under the best storage and handling conditions, however, deterioration does occur. Little can be done to advance our knowledge until we know more of the physical chemistry of the proteins present. This is the line of endeavor on which we are working at present.

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MICROBIOLOGICAL FORMATION OF VITAMIN B_{12}

I. PRODUCTION IN FISH PRESS LIQUID[1]

By H. L. A. Tarr

Abstract

Vitamin B_{12a} was formed by *Streptomyces griseus* species and by *Streptomyces aureofaciens* in aerated herring press water containing 2 μgm. per ml. of added cobalt (as cobaltous nitrate). The yield of the vitamin was improved by diluting the press liquid (stickwater) to 2% solids content. No consistent agreement was obtained in vitamin B_{12} assays of the crude fermentation liquors by two very different procedures. Highest apparent recovery of vitamin B_{12a} in these products (about 1100 mμgm. per ml. with *S. aureofaciens* and 800 mμgm. per ml. with *S. griseus*) was obtained by chromatography on potassium dihydrogen phosphate-treated filter paper strips, elution of the vitamin, and aseptic addition of the eluates to previously sterilized *Lactobacillus leichmannii* assay medium. Treatment of the crude fermentation products with potassium cyanide (2.5 mgm. per ml.) caused partial resolution of the vitamin B_{12a} to vitamin B_{12}.

Introduction

Though vitamin B_{12} was first obtained from liver (6, 18, 23) its isolation from *Streptomyces griseus* cultures was announced shortly afterward (19). However, very little information has as yet been made available regarding the media used, fermentation conditions, or yield of vitamin B_{12} by *Streptomyces* species. Hendlin and Ruger (10), in studying the influence of cobalt on vitamin B_{12} formation, recorded with *S. griseus* a yield of 3500 LLD units (about 320 mμgm.) of vitamin B_{12} active substances per ml. of a medium containing enzymic casein digest, beef extract, and about 2 μgm. per ml. of cobaltous ions. The role of cobalt in improving the yield of vitamin B_{12} in an aerated medium containing 10% sucrose and inoculated with *Bacillus megatherium* was recognized independently by Lewis and associates (8, 14). These investigators reported maximum yields of 800 mμgm. of alkali labile vitamin B_{12}-active substances per ml. of medium. The formation of vitamin B_{12}-active substances by various bacteria has been reported (10, 25), though the amounts formed appear to have been usually considerably lower than those recorded by the above workers. Very small yields of vitamin B_{12} were reported in nonaerated cultures of microorganisms isolated from poultry house litter (9).

Recent work has shown that several forms of vitamin B_{12} may occur (1), and this property has been attributed to the ability of the cobalt moiety to form co-ordination complexes with different ions (5). Vitamin B_{12} is regarded as a cyano cobalt co-ordination complex (11) or "cyano cobalamine", and vitamin B_{12a} as the corresponding hydroxy complex (5). It is now generally accepted that *Streptomyces* species form largely vitamin B_{12a} (7, 15), and that this form is identical with vitamin B_{12b} (1, 11). Vitamin B_{12a} has been found

[1] *Manuscript received March 27, 1951.*
Contribution from Pacific Fisheries Experimental Station, Vancouver, B.C.

to yield much lower results in an assay procedure using *Lactobacillus leichmannii* than in a rather similar procedure using *L. lactis* (27). Thus it has been stated recently that autoclaving vitamin B_{12a}, in an *L. lactis* assay medium which contains no added reducing agent such as ascorbic acid, occasions about 30% destruction of the vitamin (11). It appears probable that the almost universal employment of reducing agents in *L. leichmannii* assay media may be responsible for the extensive destruction of vitamin B_{12a} which occurs during autoclaving (27). This contention is supported by the report that vitamin B_{12a} is much less stable in presence of ascorbic acid than is vitamin B_{12} (26), though vitamin B_{12} is itself unstable in the presence of ascorbic acid and other reducing agents if the concentration is fairly high (13).

The present work was undertaken with the object of determining the feasibility of enhancing, by microbiological fermentation, the natural, rather variable, vitamin B_{12} content of fish materials (17, 25). The results obtained in preliminary experiments have been described previously (24, 25).

Cultures, Materials, and Methods

S. aureofaciens and five strains of *S. griseus* obtained from different laboratories were used, and were maintained by weekly transfer on Bacto nutrient agar followed by room temperature incubation. For microbiological assay of vitamin B_{12} *Lactobacillus leichmannii* (A.T.C.C. No. 4797) and a vitamin B_{12}-requiring *Escherichia coli* mutant (British N.C.I.B. No. 8134) were employed.

Herring press liquid (October 1948) was frozen and stored at −20°C. to −28°C. until required for the fermentation experiments. This material is known to be a fair source of essential amino acids (16). The particular sample used contained 7.8% total solids, 0.95% ash, 0.85% sodium chloride, and its pH was 6.8. In one experiment a tryptic casein digest–beef extract medium (10) was used (pH 6.8), the tryptic digest being prepared by the method of Kitay, McNutt, and Snell (12), except that it was not adsorbed with charcoal.

Fermentation of the press liquid with *Streptomyces* species was carried out as follows. The material, containing 2 μgm. per ml. of added cobaltous ions (10), was sterilized for 15 min. at 120°C. either in 25-ml. quantities in 3 × 20 cm. test tubes, or in 150-ml. quantities in 7 × 28 cm. Pyrex wash bottles. The containers were closed with rubber stoppers which were equipped with the conventional glass inlet and exhaust tubes for aseptic aeration of the medium. In the smaller containers, glass tubes with constricted tip were used for aeration, while in the larger containers, coarse sintered-glass Pyrex discs were employed for this purpose. The press liquid was inoculated with a small piece of the growth from a two-day nutrient agar culture of the *Streptomyces* species being studied, and it was then aerated vigorously at 28°C. with air sterilized by passage through dilute sulphuric acid, dilute sodium hydroxide,

sterile absorbent cotton, and sterile distilled water. Serious foaming rarely occurred, and in the occasional instances where it did occur, it was counteracted successfully by addition of a few drops of sterile herring oil. Small samples of culture liquid were removed at intervals for vitamin B_{12} assay, and the volume was kept constant by addition of sterile distilled water.

Two methods of vitamin B_{12} assay were used. In the first, the tube assay technique described by Skeggs, Nepple, Valentik, Huff, and Wright (22) was followed with the following minor modifications. The double strength medium was adjusted to pH 6.9, and *l*-ascorbic acid (1 mgm. per ml.) was added immediately before automatically dispensing 2-ml. quantities in 18 × 150 mm. tubes, the final pH being 6.5. In most experiments, vitamin B_{12} solution (0.2 mμgm. per ml.), or appropriately diluted fermentation product, was added, together with distilled water, to bring the total volume to 4 ml. prior to sterilizing for five minutes at 120°C. However, when the advantage of adding vitamin B_{12a}-containing materials aseptically to the previously sterilized medium was realized (*vide infra*), this modification was employed. In order to facilitate the rapid uniform growth essential for satisfactory turbidimetric assays it was found advantageous to inoculate each tube with 0.1 ml. of a 1:100 water dilution of a 16-hr. culture of *L. leichmannii* grown in the assay medium containing 0.1 mμgm. per ml. of vitamin B_{12}. The vitamin B_{12}-containing broth cultures used for inoculation were prepared from stock cultures each week, transferred daily, incubated for 16-18 hr., and kept at 0°C. until subsequent transfers were made. *L. leichmannii* assays were incubated at 37°C. for 18 hr., the amount of growth being determined turbidimetrically using a Beckman model DU spectrophotometer set at 540 mμ and 0.1 mm. slit width. Tests showed that approximately 20,000 times as much thymine or guanine deoxypentoside as vitamin B_{12} was required to give similar growth response in this assay.

The second assay method employed was a cup-plate procedure using a simple inorganic salt-glucose medium solidified with 2% agar and inoculated with the *E. coli* mutant (2, 3). With this method the diameter of the growth-exhibition zones varied directly with the logarithm of the concentration of vitamin B_{12} when concentrations of the order of from 1 to 1000 mμgm. per ml. were placed in the assay cylinders. Fermentation products were adjusted to pH 6.8 and heated 30 min. at 100°C. before being assayed by this method.

Separation of vitamin B_{12} and B_{12a} in fermentation products was effected by chromatography on potassium dihydrogen phosphate treated Whatman No. 1 filter paper strips with water-saturated *n*-butanol as solvent (27). Experience showed that for quantitative recovery, it was advisable to apply 0.02 to 0.10 ml. of the fermented liquid to the strip, the larger volumes being spotted by several successive applications of 0.01 or 0.02 ml. An Agla micrometer syringe proved useful for these applications, particularly since fermentation products containing rather large mycelial "pellets" could be "emulsified" by repeated passage through the glass nozzle. All operations were

carried out either in the dark or in subdued light. Duplicate strips were always prepared, and the position of the vitamin B_{12} and vitamin B_{12a} was located by "developing" one strip on the inorganic salt – glucose agar medium inoculated with the *E. coli* mutant. With this method, growth zones corresponding to vitamin B_{12} or B_{12a} developed in about six hours at 37°C., but, for convenience, an overnight incubation temperature of 28°C. was generally used. Quantitative vitamin B_{12} or B_{12a} determinations were carried out using aqueous solutions obtained by eluting corresponding areas on the duplicate filter paper strips into sterile distilled water in experiments in which aseptic additions were made to the assay medium.

Thymine deoxyriboside (m.p. 186° – 187°C.; Micro block) was made by the method of Brady (4) and guanine deoxyriboside by that of Schindler (21).

Experimental

In order to test the reliability of the *L. leichmannii* vitamin B_{12} assay method, five determinations were carried out at different times on herring press water with the following results: 97, 97, 102, 103, and 105 mμgm. per ml. (average 101). This experiment indicated that the results obtained with this crude material were reproducible within limits of ± 4%. A similar degree of accuracy can normally be obtained with aqueous extracts of fish or mammalian tissues or organs. However, as will appear later, the recovery of vitamin B_{12} in fermentation products depends to an important extent on factors other than the accuracy of the assay technique itself. The same material, when assayed by the *E. coli* cup–plate method, had an apparent vitamin B_{12} concentration of 75 mμgm. per ml. Vitamin B_{12} formation by all six *Streptomyces* species was studied in a number of preliminary experiments using 25-ml. portions of undiluted press liquid. There was no very pronounced difference in the amount of vitamin B_{12} produced by the various organisms under the experimental conditions, therefore only two of the *S. griseus* cultures, and *S. aureofaciens*, were subjected to more detailed study.

The results obtained in four experiments using undiluted herring press liquid are recorded in Table I. There was an apparent decrease in the vitamin B_{12} content of the aerated sterile press liquid (controls), and whether this was due to actual destruction or change to a form (e.g. vitamin B_{12a}) which yielded lower results in the normal assay procedures with *L. leichmannii* (*vide infra*) was not determined. With all *Streptomyces* species there was a definite but limited increase in the vitamin B_{12} content. In these, and in subsequent experiments, antibiotic produced by *S. aureofaciens* usually markedly suppressed growth in *L. leichmannii* assays.

In a subsequent experiment the yield of vitamin B_{12} in herring press liquid diluted to 2% solids content, and in casein digest – beef extract medium, was determined by the two different assay techniques. The susceptibility of the vitamin B_{12}-active substances, formed in these media, to destruction when

heated for 30 min. at 100°C. in 0.2 *N* sodium hydroxide, was also determined in some instances. The results of a typical experiment are given in Table II. There was a marked increase in the vitamin B_{12} content of both substrates, especially after four days' fermentation, the increase being most marked with

TABLE I

VITAMIN B_{12} CONTENT OF UNDILUTED HERRING PRESS LIQUID AFTER FERMENTATION WITH *Streptomyces* SPECIES

Experiment No.	Period of fermentation (days)	Vitamin B_{12} (mμgm. per ml.)			
		Control (uninoculated)	*S. griseus* A.T.C.C. 10137	*S. griseus* 3478	*S. aureofaciens*
1	4	55	220	180	260
2*	2	50	140	160	210
3	2	75	100	...	...
	3	50	190	160	**
4	2	50	120	150	**

**Inoculated with fermented material from the corresponding sample in Expt. 1.*
***Antibiotic present prevented tube assays from being carried out successfully.*

TABLE II

VITAMIN B_{12} CONTENT OF HERRING PRESS LIQUID DILUTED TO 2% SOLIDS CONTENT, AND OF A CASEIN DIGEST – BEEF EXTRACT MEDIUM, AS DETERMINED BY TWO DIFFERENT MICROBIOLOGICAL ASSAY PROCEDURES CARRIED OUT ON FERMENTED LIQUIDS

	Vitamin B_{12} (mμgm. per ml.)			
	Fermented 2 days		Fermented 4 days*	
	L. leichmannii assay	*E. coli* assay	*L. leichmannii* assay	*E. coli* assay
Herring press liquid				
Uninoculated	1.8	2.0	3.4	12.0
Inoculated with:				
S. griseus 10137	240	150	480(0.6)	750(0)
S. griseus 3478	90	55	250(0.4)	750(0)
S. aureofaciens	...	150	250(0.2)	1300(0)
Casein digest – beef extract medium				
Uninoculated	0.05	...	0.2	...
Inoculated with:				
S. griseus 10137	180	170	200(2.2)	750(2.5)
S. griseus 3478	60	40	100(3.0)	600(2.0)
S. aureofaciens	...	About 5	...	180

* *The bracketed figures are the results obtained after heating the samples in 0.2 N sodium hydroxide for 30 min. at 100°C.*

S. griseus A.T.C.C. No. 10137 and *S. aureofaciens*. In general, the yield of vitamin B_{12} was higher in the press liquid than in the casein digest – beef extract medium. There was no agreement between results of assays by the tube and the cup–plate methods, though the results obtained by the latter method were invariably considerably higher after four-day fermentation. Treatment with alkali under conditions which are known to lead to destruction of vitamin B_{12} caused complete, or almost complete, elimination of vitamin B_{12}-active substances. Difficulty was again experienced in obtaining satisfactory vitamin B_{12} assays with the *S. aureofaciens* products, particularly in the casein digest medium.

A further experiment was made in which 150-ml. quantities of press liquid, adjusted to 2% solids content, were fermented, and samples were withdrawn at intervals for microbiological assay for vitamin B_{12} by the two different methods. The results (Table III) show a definite increase in vitamin B_{12} in

TABLE III

VITAMIN B_{12} CONTENT OF HERRING PRESS LIQUID DILUTED TO 2% SOLIDS CONTENT AS DETERMINED BY TWO DIFFERENT MICROBIOLOGICAL ASSAY PROCEDURES CARRIED OUT ON THE FERMENTED LIQUORS

Days fermented	Vitamin B_{12} (mμgm. per ml.)					
	S. griseus No. 10137		*S. griseus* No. 3478		*S. aureofaciens*	
	L. leichmannii assay	*E. coli* assay	*L. leichmannii* assay	*E. coli* assay	*L. leichmannii* assay	*E. coli* assay
2	110	380	70	50	20	330
3	320	500	110	110	100	100
4	460	250	150	170	310*	120
5	390	180	190	170	220*	50

* *Strong growth suppression in the lower dilutions rendered accurate assays impossible.*

the fermented press liquid, especially with *S. griseus* A.T.C.C. No. 10137 and *S. aureofaciens*. Again there was no agreement between the two vitamin B_{12} assay methods except with the *S. griseus* No. 3478 fermentation product. With the other two products there was a tendency for the *L. leichmannii* assay to indicate a steady increase in vitamin B_{12} up to the fourth day, while with the *E. coli* method there was an apparent decrease in vitamin B_{12} during the latter part of the fermentation. These findings, when taken in conjunction with those reported in the foregoing experiments, indicate that direct assay of crude fermentation products for vitamin B_{12} may not yield very reliable results.

In view of the variable results obtained in the direct assay of the crude fermentation products for vitamin B_{12}, concentration and partial purification of the vitamin by chromatographic separation on filter paper strips, followed by elution and microbiological assay of the eluates, was carried out. Since

previous work (25) had indicated that chromatography using ordinary untreated filter paper strips cannot always be relied upon to separate vitamin B_{12} from interfering vitamin B_{12}-active substances, the method of Woodruff and Foster (27), by which vitamin B_{12} and B_{12a} are separated not only from interfering substances but also from each other, was adopted. Since vitamin B_{12} is unstable toward light (6) all chromatographic procedures were carried out either in the dark or at least in subdued light.

Preliminary trials with crystalline vitamin B_{12} verified the fact that only about 90% of the vitamin B_{12} chromatographed is recovered as such, and that the remainder appears as vitamin B_{12a} (27). The results given in Table IV

TABLE IV

RECOVERY OF VITAMIN B_{12} AND B_{12a} USING CHROMATOGRAPHY OF CRYSTALLINE VITAMIN B_{12} ON KH_2PO_4 TREATED FILTER PAPER, FOLLOWED BY ELUTION AND *L. leichmannii* ASSAY OF THE AQUEOUS ELUATES

Vitamin B_{12} applied (mμgm.)	Vitamin B_{12}, mμgm.		Vitamin B_{12a}, mμgm.	
	Expected*	Recovered	Expected**	Recovered
150	135	133	15	1.8
"	"	139	"	6.2
75	67.5	62	7.5	0.44
"	"	65.3	"	1.24
15	13.5	13.6	1.5	0.46
"	"	13.9	"	0.56
7.5	6.75	6.8	0.75	0.36
"		6.51	....	....
1.5	1.35	1.60	....	....
"		1.49		

* *Assuming 90% of the vitamin B_{12} applied appears as such.*
** *Assuming 10% " " " B_{12} " " " vitamin B_{12a}.*

show that, within reasonable limits of error, it was possible to recover almost quantitatively all the vitamin B_{12} when amounts of from 1.5 to 150 mμgm. were applied to the paper strips. Very poor and variable recovery of the expected vitamin B_{12a} was experienced, and in view of later work (*vide infra*), it would appear that autoclaving of this form of the vitamin in assay medium containing ascorbic acid, was responsible for the loss.

It was found that separation of the vitamin B_{12} and B_{12a} in press liquid fermentation products could be effected by spotting 0.01 to 0.10 ml. on potassium dihydrogen phosphate treated filter paper strips and developing these for 48–52 hr. at 37°C. In these products, especially after prolonged fermentation, all, or nearly all, of the vitamin occurs as vitamin B_{12a}.

All subsequent quantitative studies were carried out using the five-day *S. aureofaciens* and *S. griseus* A.T.C.C. 10137 products from the foregoing experiment, these being stored under benzene at 0°C. The *S. griseus* product was rather viscous and considerable autolysis of the mycelia seemed to have

occurred, while the *S. aureofaciens* product contained masses of mycelial pellets. The *S. griseus* product was chromatographed in 0.02- or 0.10-ml. amounts, and the vitamin B_{12a} zone was eluted and assayed by *L. leichmannii* procedure. Values of 325, 355, 385, and 420 mμgm. per ml. were obtained in separate assays. The average value, namely 366, was very similar to that obtained in direct assay of the product.

At this stage, it became apparent that the *L. leichmannii* assay procedure would have to be modified in order to avoid extensive destruction of vitamin B_{12a}. Preliminary tests showed that aseptic addition of the appropriately diluted fermentation products, or eluates containing vitamin B_{12a}, to the separately sterilized assay medium gave considerably higher recovery than did their sterilization when included in the assay medium. A series of experiments was therefore carried out with the object of determining the optimum assay conditions for the determination of vitamin B_{12a} in fermentation products. In this work the following conditions were investigated: (1) aseptic addition of the unheated product, suitably diluted, to the previously sterilized assay medium, (2) identical with (1) only the product was adjusted to pH 6.8 and heated 30 min. at 100°C., (3) identical with (1) only the product was adjusted to pH 6.8 and heated 15 min. at 120°C., (4) the product was chromatographed, eluted, added to the assay medium, and sterilized as usual, and (5), identical with (4), only the eluates were added aseptically to the previously sterilized assay medium. The results of these experiments, which are recorded in Table V, show that the conditions under which microbiological assays of crude fermentation products are conducted have a very important bearing on the apparent recovery of vitamin B_{12}.

With the *S. griseus* product addition of the crude diluted material itself, or of aqueous eluates from filter paper chromatograms, to the assay medium before sterilization yielded rather similar assay values (385 to 420 mμgm. per ml.). Considerably higher values resulted when neutral aqueous solutions of the crude fermentation product were heated at 100° or 120°C. and were then added, after suitable dilution, to the separately sterilized assay medium. This procedure has the advantage that heating is believed to release "bound" forms of vitamin B_{12}(20), and that it avoids, to some extent at least, destruction of vitamin B_{12a}. When chromatographic separation of the vitamin B_{12a} followed by aseptic addition of the eluates to sterile assay medium was employed, even higher apparent recovery of the vitamin resulted. With the *S. aureofaciens* product results were somewhat confused by the fact that antibiotic produced made the direct assay of the crude material very difficult. However, with this product the highest apparent vitamin B_{12a} yield also resulted when chromatographic separation followed by aseptic addition of eluates to the sterile assay medium was employed. It is suggested that, at least until further information becomes available, this last named technique is more liable to yield reliable information concerning the vitamin B_{12a} content of fermentation products than are the other methods.

TABLE V

EFFECTS OF MICROBIOLOGICAL ASSAY CONDITIONS, AND CHROMATOGRAPHIC SEPARATION PRIOR TO ASSAY, ON THE APPARENT VITAMIN B_{12a} CONTENT OF FERMENTATION PRODUCTS

Treatment	Vitamin B_{12a} (mμgm. per ml.)	
	S. griseus product	*S. aureofaciens* product
Original values obtained by addition of a 1: 1000 dilution of the products to the medium prior to sterilization	390	220*
A 1: 2000 dilution of the unheated product added aseptically to the previously sterilized medium	400	560*
Product heated at pH 6.8 for 30 min. at 100°C. and added aseptically to the sterilized medium as a 1: 2000 dilution	590	490*
Product heated at pH 6.8 for 15 min. at 120°C. and added aseptically to the sterilized medium as a 1: 2000 dilution	650	530*
Product (0.02 ml.) chromatographed and the eluate added to the medium prior to the sterilization	420	850
Product (0.10 ml.) chromatographed and the eluate added to the medium prior to sterilization	385	830
Product (0.02 ml.) chromatographed and the eluate added aseptically to the previously sterilized medium	740 880	1020 1040
Product (0.10 ml.) chromatographed and the eluate added aseptically to the previously sterilized medium	830	1040 1140

* *These figures are not very accurate since antibiotic present prevented growth in assay tubes containing the lower dilutions.*

It has recently been reported that treatment of crystalline vitamin B_{12a} with cyanide at pH 5–6 causes conversion of this "hydroxy cobalamine" form to the "cyano cobalamine" form (vitamin B_{12}) (11). Treatment of the crude fermentation products at room temperature and pH 5.5 with about the same concentration of potassium cyanide (2.5 mgm. potassium cyanide per ml.) as used in the above work caused a partial conversion of the vitamin B_{12a} to vitamin B_{12} as indicated by quantitative chromatographic separation of the two forms on potassium dihydrogen phosphate treated filter paper strip, elution, and microbiological assay (Table VI). The results obtained in the

TABLE VI

PARTIAL RESOLUTION OF VITAMIN B_{12a} TO VITAMIN B_{12} IN FERMENTATION PRODUCTS TREATED WITH POTASSIUM CYANIDE

Cyanide treated product chromatographed	Vitamin B_{12} (mμgm. per ml.)	Vitamin B_{12a} (mμgm. per ml.)	Total (vitamin B_{12} + vitamin B_{12a})
S. griseus product, 0.10 ml.	198	175	373
" " , 0.10 ml.	168	208	376
" " , 0.01 ml.	100	260	360
S. aureofaciens product, 0.10 ml.	175	257	432
" " , 0.02 ml.	173	253	426

assay of the vitamin B_{12a} are probably low, since the experiments were carried out before it was realized that better recovery of this form of the vitamin could be obtained by aseptic addition of the eluates to the previously sterilized assay medium.

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SECTION FIVE

Resources of Arctic and Subarctic Seas*

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Presented by N. J. BERRILL, F.R.S.C.

IT has become the fashion, quite recently, to develop the north. Institutes, new government departments, discussion groups, have been formed to consider, assist, and effect the study and development of the arctic and subarctic regions—all in the past five years or so. To those of us who were interested in these problems many years before the present outburst of energy, this sudden preoccupation with the north seems over-enthusiastic and somewhat late. Over-enthusiastic, because claims are being made concerning possibilities in the north which certainly are founded upon very little observation; and late, because if the study of the north had been made steadily over the past fifty years we would have established the habit of northern research by this time, and would not have to be over-enthusiastic to stimulate interest and loosen the purse-strings.

As usual, the present trend has followed the land-bound habits of human beings, and there is an overwhelming emphasis upon the land rather than on the sea. It is true that the resources of the greatest potential value in dollars and cents, minerals, lie in the land, but it should not be forgotten that for more than a thousand years it has been upon the sea and not upon the land that man has relied for his support in northern parts of the world. The traditional Eskimo way of life is one of hunting, mostly on salt water. The Norsemen's colonization of west Greenland some nine hundred years ago was made possible largely by the resources of the sea, and the same is true of the Danish development in Greenland today. Furthermore, the first commercial interests in the north lay in whaling and sealing and in fishing, not in prospecting or in mining.

We have destroyed, at least for a time, the whaling industry in the north; we seem to be fast doing the same thing in the south. The sealing conditions are not the healthiest possible today, owing to the

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lack of a unified code of behaviour among the nations concerned. These are serious matters, both for the Eskimo population and for ourselves as civilized people. I believe that the time has come to take stock of these marine resources of the north, not in order to develop them ultimately in commerce, but simply in order to provide, for Eskimo development, a sound basis for the Eskimo economy. A sound Eskimo economy, based on the local resources, would be a great saving to our pocket-book; and it would be of immense value when the time comes, as it very soon will, to integrate the activities of the Eskimo population with our own in the north.

The traditional Eskimo hunting economy was largely dependent upon the sea. It was, moreover, dependent mainly upon the mammals of the sea, the seals and the whales. This was because the habitat and migration routes of the Eskimo had long been the shores of the arctic region, not the subarctic. The arctic waters are, or were, rich in mammals, but not in fishes. It is in the subarctic waters that fisheries can be, and have been, developed, but we may observe that even when the Eskimos came down into subarctic marine regions, where the development of considerable fisheries was possible, they still did not develop them until the arrival of the white man brought help and encouragement. The Eskimos are a very conservative people, and do not lightly turn from the ways of their forefathers to new patterns of economy—except of course where obvious rewards are immediately forthcoming, as in the sale of furs or souvenirs to the white man. In west Greenland, a markedly subarctic area, it was the Danes who developed the present native fishery; on the Labrador coast the great wealth in codfish and other species was not seriously touched before the arrival of the Moravians in the eighteenth century (Tanner, 1947). Indeed, it may well be supposed that a fishery of any size cannot be maintained without the help of civilized technology.

It is to this important difference between the arctic and subarctic marine regions that I wish to give special attention here. The delimitation of the arctic from the subarctic on land has been attempted by many students, using a variety of criteria; but no single criterion, or set of criteria, has so far been able to satisfy everyone. Furthermore, it is quite clear from the dividing limits so far published that the authors consider the sea of no importance, for once their limiting lines leave the land and begin to cross salt water they make no sense at all. They are apt, for instance, to depart from Belle Isle or Hamilton Inlet in a straight line for Cape Farewell, thus relegating to the arctic not only the Atlantic water in the west Greenland current, but even the obviously non-arctic water of the Labrador Sea.

In the marine environment, the delimitation of the two regions is much simpler, but it must be done for the sea only, without reference to the terrestrial conditions. If we define the "arctic" as those parts in which the water, or at least the surface layers (100-200 metres), is of polar origin (from the polar sea); the "boreal" as those parts of the temperate northern hemisphere in which the sea water is of purely Atlantic or Pacific origin; and the "subarctic" as those parts in which both kinds of water are found in the upper layers, then we have a sensible and indeed obvious system in which the lines of delimitation, although they may change position somewhat from season to season and from decade to decade, are fairly easy to draw at any given time. The fact that they change in position is indeed a virtue, since they thus reflect a dynamic and not a static system. Such a system of delimitation has already been published (Dunbar, 1951).

As a rule these three water types (arctic, boreal, and mixed) can be distinguished quite easily by physical and chemical means alone. The arctic water is very cold, usually below 0° C., and of low salinity, always below 34 ‰ and often below 33 ‰. The Atlantic water is much warmer, above 4° C. at least, and of higher salinity, always above 34 ‰ unless greatly influenced by coastal drainage. The subarctic water lies naturally between these two in both parameters. Thus the west Greenland water, of 2 to 3° C. and 33 to 35 ‰, is obviously subarctic. But there are occasions when these criteria are not adequate, and in such cases we have to call upon living indicators which are known to be limited to non-arctic water, and are therefore, in the extreme limits of their distribution, useful as indicators of the northern limits of the subarctic. These indicators are necessary, for instance, to assess the nature of the water of Ungava Bay. It may be argued that if these indicator species (Atlantic cod and Atlantic salmon are two good examples) are restricted to water of boreal or subarctic parameters, then how is it that they are also found where the significant values of these physical parameters are not apparent? The answer is, I believe, that the characteristics of temperature and salinity may be obscured by local conditions of freshwater drainage and vertical turbulence, which disturb our observations more than they disturb the codfish and the salmon.

The arctic marine region is rich in mammals but poor in fishes. I do not believe that this is caused specifically by differences in productivity between arctic and other water (although such differences do exist), so much as by the fact that the mammals are homoiothermous and the fishes poikilothermous, and hence that the process of recolonization of the arctic water since the last glaciation presented

less difficulty to the former than to the latter. It is to be expected that within the next few thousand years, or tens of thousands of years, the fishes of the present subarctic, or their evolved descendants, will have invaded the arctic waters. At present, however, it seems that for most fishes the very low temperatures of arctic water present a condition which renders growth and reproduction impossible. It is worthy of notice that the Cottidae, better represented in arctic waters than any other family of fishes, are generally considered to have dispersed in postglacial times from a Bering Sea refuge, where they should have been, from the start, acclimatized to low temperatures; and that the Coregonidae have come to North America from a Siberian refuge. Speculation is also legitimate here about the date of arrival in arctic water of the invertebrate groups which, with their lower organization and presumably greater lability, shorter generations, and greater breeding potential, might be expected to overcome low temperature and other barriers in a shorter time than other poikilotherms.

Be that as it may, there is no doubt (1) that the only fish of economic significance in arctic sea water is the arctic char (*Salvelinus alpinus*); (2) that the possibilities of important salt water fisheries are to be found in subarctic and not in arctic waters; and (3) that there is an obvious difference in the quantities of living matter produced in the two types of water, the greater production by far being in the subarctic. There has as yet been very little quantitative study made of this last point, largely because arctic marine research is still young enough to demand predominantly qualitative attention; but even without the use of quantitative methods for measuring plankton production (methods which are still open to considerable suspicion), the difference in the results of hauling plankton with ordinary open nets in arctic and subarctic water is most striking. Thus, throughout the open water season, the same plankton net, hauled for the same time, and with all conditions equal, will yield very much less plankton in the arctic water of the Baffin Island coasts than in the rich subarctic waters of west Greenland or Newfoundland, the ratio of the quantities being roughly between 1 : 3 and 1 : 6 or more, depending on the locality.

It is, so far as we know at present, only in temperature that arctic and subarctic waters differ significantly, at least in relation to this difference in productivity. It is therefore in the temperature difference that we should first look for the explanation of the phenomenon. Subarctic water is always water in which polar and non-polar water come together, and we have therefore to examine the histories of the two water types before junction or mixing occurs. The Atlantic water

has no special characteristics, other than the higher temperature, to which we can point as relevant to the present discussion; but the arctic water has several.

The lower temperature allows high concentrations of dissolved gases, so that carbon dioxide and oxygen are present in abundance in polar water. This has been confirmed by empirical observation. Neither oxygen nor carbon dioxide, however, appear to be limiting factors in production in the sea generally, so that polar water is not exceptional in the possession of excess gases. The high concentrations, however, are important as indices of high potential production.

Neither phosphates nor nitrates are normally limiting factors in the sea (except possibly temporarily, in midsummer) so that their concentrations in arctic water are not immediately relevant to the matter in hand. Indeed, little study has been made of the concentration of these salts in the north. Measurements in west Greenland and in the Labrador, both subarctic regions, have shown normal levels. The only special condition which arctic water shows in this respect is the high population of sea-birds in spring and summer, which provides a mechanism for the immediate return of nutrient salts to the surface water, via the birds' faeces, without the necessity of vertical exchange of water. This is well demonstrated in the vicinity of breeding bird colonies in subarctic regions, where the water is often thick with diatom growth all summer long, in contrast to the surface elsewhere, which presumably becomes exhausted of nutrients in midsummer. This effect appears to be much less marked in arctic water, where apparently the growth is kept down by low temperature.

The long days of the northern summer most probably favour the growth of the phytoplankton, although there has been no definitive experimental work to show just what their precise effect is.

This high potential for the production of life in arctic water clearly is not realized until admixture with non-arctic water takes place, in the subarctic. The obvious inhibiting factor is the low temperature. Upon contact with the warmer Atlantic (or Pacific) water, this inhibition is removed, and the result is the great blossoming of life which has been described. The turbulent nature of subarctic water, with low stability, no doubt assists this process.

It has been pointed out, however, that these factors of potential production in arctic water (gases, phosphates, and nitrates) are seldom if ever considerable limiting factors in the life of the sea, and the question arises as to whether or not they can therefore explain entirely this great subarctic release of energy. Nor can it be said that the length of the summer days is the deciding factor, for the subarctic regions are not in

equal latitudes. It may be, therefore, that there is some other character of arctic water which is perhaps of first importance in this matter, and I would suggest here that the possibility that this factor is one of the molecular structure of the water itself should not be overlooked.

I am aware that in discussing the molecular structure of water I am invading a field outside my own; it is also a field which is at present a controversial one, even within the circles of physicists and physical chemists who know most about it. The controversy, however, concerns the specific polymers found in water, rather than the very existence of the polymers themselves. It appears to be generally agreed that the most reasonable explanation of the anomalies of the behaviour of water, considered as consisting of uniform monohydrol (H_20) molecules, is that water in fact consists of polymers of the monohydrol in equilibrium; and that the state of the equilibrium depends in part upon the temperature of the water and in part upon its recent history. The disagreement enters when the proportions of the polymers present under given conditions, and the number of monohydrols within those polymers, are considered. This is not a point which concerns us here, and in discussing the relevance of the polymers to the production of life in the sea, it should be understood that when the term "trihydrol" is used here (the trihydrol being one of the more popular polymers), it is used simply to denote the largest aggregate commonly present in water, whatever it may finally turn out to be.

In theory, the trihydrol (or other polymer) is at its greatest concentration in ice, and in the liquid medium is dominant in water recently melted from ice. It is at its minimum concentration in steam, and in water recently condensed from steam, in which the monohydrol dominates. Arctic water contains at all times, and especially in spring and summer, an unestimated large amount of water recently melted from ice, and therefore should contain a high proportion of the trihydrol (or other water polymer), even allowing for the presence of solutes, which appear to simplify the physical behaviour of water and which have even been supposed to break up the water polymers in high solute concentrations.

Some seventeen years ago experiments were done by Barnes (1932), Barnes and Jahn (1933), and by Harvey (1933), all showing that water recently melted from ice had a decidedly stimulating effect on the growth and multiplication of green cells (*Spirogyra*, *Euglena*, *Nitzschia*). In the case of *Euglena*, for instance, Barnes and Jahn (1933) found that the average increase in the number of cells in the condensed steam water, in experiments of ten to sixteen days' duration, was 32 per cent, while the increase in the ice water culture was 105 per cent. The pH

of the two water types was the same, from which it was inferred that the CO_2 concentration was approximately the same in both. The effect has also been observed in cultures of *Bacterium coli* (Hegarty and Rahn, 1934); in the experiments in question air was bubbled through the water samples to avoid any effect from oxygen deficiency.

It is to be hoped that there will be evolved, in due course, a method of measuring the proportion of higher water polymers directly; so far, efforts in this direction have not been successful. In the meantime, there seems to be no better way of explaining the results of the experiments I have mentioned than by assuming that the polymers do exist, that their concentration is a function of the recent history of the water, and that they stimulate, in a manner not yet known, the growth and multiplication of holophytic cells. Barnes and Jahn (1934) suggested that this effect might help to explain the "richness of plant forms in arctic water." I believe that this effect may be very important, although clearly the question is one of an increase in the *potential* for production in arctic water rather than in the actual production. It is probable that one important contribution of arctic water to the subarctic, where the temperature inhibition is removed, is in fact ice water.

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